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HEAPREC

A Methodology For Determining Cyanide Heap Leach Reclamation Performance Bonds

U.S. Bureau of Mines

By David K. Denton, Jr., Stephen R. Iverson, and Burton B. Gosling

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UNITED STATES DEPARTMENT OF THE INTERIOR
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	m^3	cubic meter
cm/s	centimeter per second	mg/kg	milligram per kilogram
d/yr	day per year	mg/m^3	milligram per cubic meter
ft	foot	mg/L	milligram per liter
ft^2, sft	square foot	min	minute
ft^3	cubic foot	mph, mi/h	mile per hour
g	gram	ppm	part per million
gal	gallon	st	short ton
h,hr	hour	st-mi	short ton-mile
hp	horsepower	syd	square yard
hp/yd^3	horsepower per cubic yard	yd^3, cyd	cubic yard
in	inch	yd^3/h	cubic yard per hour
kW·h	kilowatt hour	%	percent
lb	pound		

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HEAPREC

A METHODOLOGY FOR DETERMINING CYANIDE HEAP LEACH RECLAMATION PERFORMANCE BONDS

By David K. Denton, Jr.,[1] Stephen R. Iverson,[1] and Burton B. Gosling[2]

ABSTRACT

This U.S. Bureau of Mines report presents the documentation for HEAPREC, a methodology for calculating reclamation performance bonds for cyanide heap leach operations. HEAPREC is a template developed for use with Lotus 1-2-3[3] release 2.01 or newer software. The report is presented in step-by-step "user's manual" format. Appendices contain detailed background and reference material on performance bonding, cyanide detoxification regulation, cyanide detoxification methods, general mine reclamation procedures, and an example bond calculation.

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[2]Supervisory physical scientist.
Western Field Operations Center, U.S. Bureau of Mines, Spokane, WA.
[3]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

INTRODUCTION

HEAPREC was developed as part of the U.S. Bureau of Mines' program to provide Federal, State, and local governments with assistance on minerals-related issues. Requirements for reclamation performance bonding of hardrock mining operations are evolving for most jurisdictions, as are the methods and procedures for determining bond amounts. Reclamation bonds are increasingly being required to ensure monies are available for reclamation if an operator abandons a property or for some reason does not complete satisfactory reclamation. HEAPREC, a template for Lotus 1-2-3 software, is a standardized methodology that can be used by Federal and State land-managing agencies to determine justifiable reclamation performance bonds for cyanide heap leach facilities.

A copy of the HEAPREC computer program can be obtained by sending one double-sided, high-density, 5-1/4 in floppy diskette to the Western Field Operations Center, U.S. Bureau of Mines, East 360 Third Avenue, Spokane, WA 99202. Requests for the program should reference this report (IC 9328).

HEAPREC was patterned after BONDCALC, a program developed by the South Dakota Department of Water and Natural Resources, Office of Minerals and Mining. The primary differences between BONDCALC and HEAPREC are that HEAPREC includes procedures for determining and accounting for costs related to cyanide detoxification of heaps and solutions and HEAPREC can be readily adapted to account for specific reclamation requirements.

An integral part of HEAPREC's documentation is the appendices. The appendices were compiled to assist the user in making decisions when working with HEAPREC. The appendices provide background and reference information on the major reclamation activities and tasks required and, within reasonable terms, how those activities might be carried out. Topics covered in the appendices include bonding (appendix A), cyanide detoxification regulations (appendix B), cyanide detoxification methods (appendix C), general mine reclamation procedures (appendix D), HEAPREC equations (appendix E), and an example bond calculation using HEAPREC (appendix F).

TEMPLATE OVERVIEW

The template and reference appendices are designed to assist the user in calculating a bond for third party reclamation of areas associated with cyanide heap leaching facilities. The costs calculated are based on the property being abandoned by the operator, therefore requiring the responsible regulatory agency to hire a contractor to complete all of the reclamation tasks.

HEAPREC accounts for costs to reclaim access roads, leach heaps, solution ponds, and areas occupied by process and ancillary buildings-structures. The accompanying appendices are designed to assist the user in the decision-making process when using HEAPREC. The template can be modified by an experienced 1-2-3 user to incorporate the reclamation costs for other mining-milling facilities, e.g., waste dumps, open pits, and tailings impoundments. However, reference and background information on these subjects are not included in the appendices.

HEAPREC users should have at least cursory knowledge of earthmoving fundamentals, revegetation principles, and cost estimation basics. HEAPREC requires the user to supply the program with inputs on types and sizes of earthmoving equipment to be used and appropriate equipment operating costs and labor rates. Selection and sizing of cyanide detoxification processes is also required. Experience in dealing with mine reclamation guidelines and common sense are also important requisites for a user.

Keystrokes

HEAPREC was designed to operate in the 1-2-3 80-column by 25-row format. This format allows the user to view 20 rows of template at a time on the computer monitor (screen) and allows for convenient movement throughout the template by screens, also referred to as ranges, set in 20-row increments. A range is defined as a two-dimensional block of spreadsheet cells identified by the upper left cell and lower right cell. LOTUS cell addresses are used throughout the text to identify a block of spreadsheet cells (i.e., A1..F20). In the 80-column by 25-row format, movement within HEAPREC is easy because each screen is aligned with the use of the **PAGE UP**, **PAGE DOWN**, or **<CTRL> LEFT** or **RIGHT** arrow key commands. By paging up, down, left, or right, the user automatically reorients to a new screen.

Template Layout

The template is roughly divided into six sections: a SUMMARY SECTION (A1..F120), an EQUIPMENT AND LABOR OPERATING COST SECTION (G1..L60), SEED and FERTILIZER COST LIST (G61..L569), EARTHMOVING AND REVEGETATION COST SITEWORK CALCULATION SECTION (A121..F881), CYANIDE DETOXIFICATION SECTION (M1..BR 199), and a section for SPREADSHEET PRINTING AND CLEARING MACROS (BY1..CN317). A general schematic of HEAPREC is shown in figure 1, and table 1 identifies and locates each specific range.

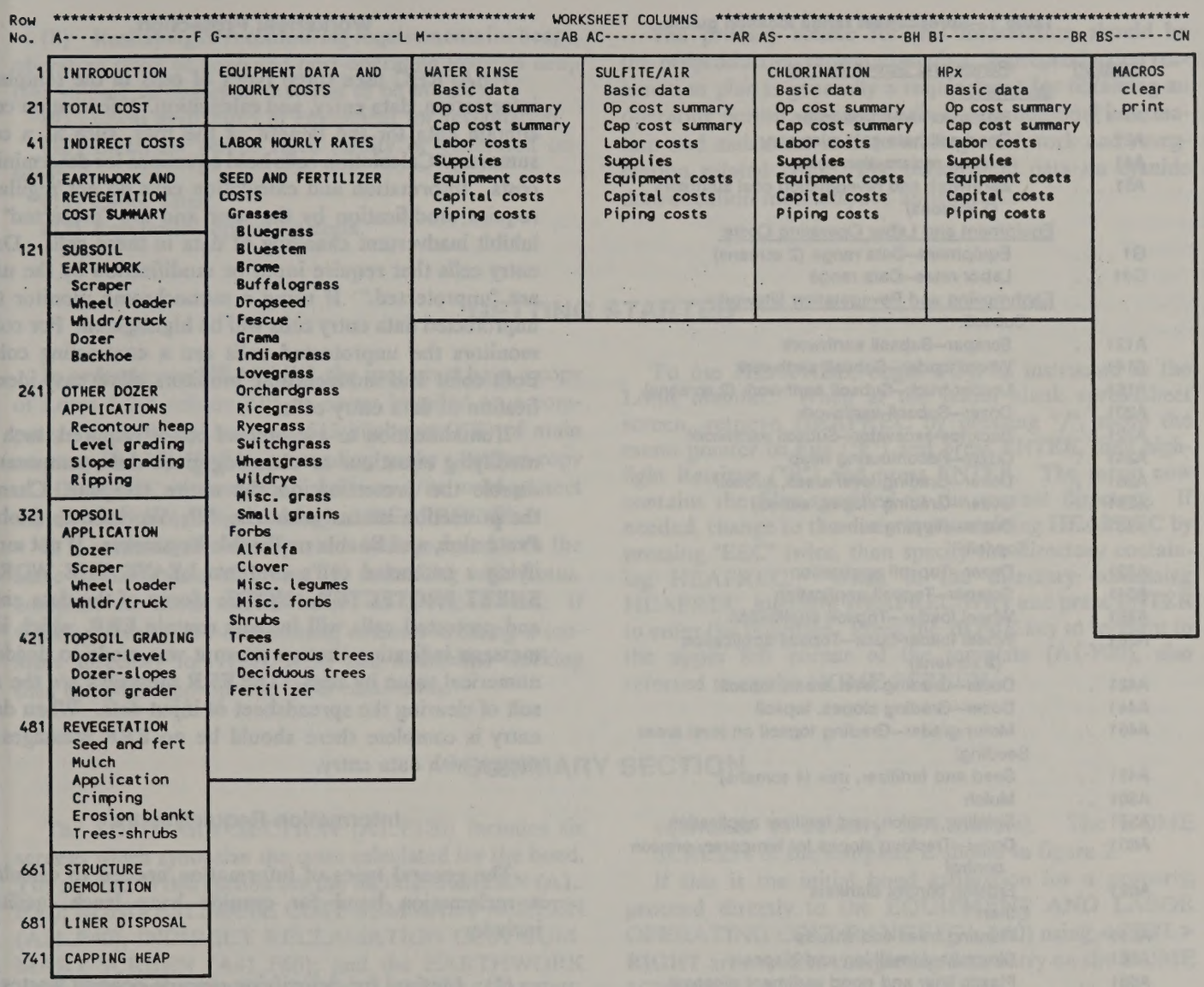


Figure 1.—HEAPREC schematic.

Table 1.—Spreadsheet range location guide

Location	Range and Screen Names
	Summaries:
A1	Home screen-Introduction
A21 ...	Bond estimate cost summary
A41 ...	Indirect reclamation costs
A61 ...	Earthwork and revegetation cost summary (3 screens)
	Equipment and Labor Operating Costs:
G1	Equipment—Data range (2 screens)
G41 ...	Labor rates—Data range
	Earthmoving and Revegetation Sitework:
	Subsoil:
A121 ..	Scraper—Subsoil earthwork
A141 ..	Wheel loader—Subsoil earthwork
A161 ..	Loader-truck—Subsoil earthwork (2 screens)
A201 ..	Dozer—Subsoil earthwork
A221 ..	Backhoe-excavator—Subsoil earthwork
A241 ..	Dozer—Recontouring heap
A261 ..	Dozer—Grading level areas, subsoil
A281 ..	Dozer—Grading slopes, subsoil
A301 ..	Dozer—Ripping subsoil
	Topsoil:
A321 ..	Dozer—Topsoil application
A341 ..	Scraper—Topsoil application
A361 ..	Wheel loader—Topsoil application
A381 ..	Wheel loader-truck—Topsoil application (2 screens)
A421 ..	Dozer—Grading level areas, topsoil
A441 ..	Dozer—Grading slopes, topsoil
A461 ..	Motor grader—Grading topsoil on level areas
	Seeding:
A481 ..	Seed and fertilizer, mix (4 screens)
A561 ..	Mulch
A581 ..	Seeding, mulch, and fertilizer application
A601 ..	Dozer—Tracking slopes for temporary erosion control
A621 ..	Erosion control blankets
	Other:
A641 ..	Planting trees and shrubs
A661 ..	Structure demolition and disposal
A681 ..	Plastic liner and pond sediment disposal (3 screens)
A741 ..	Capping heap (7 screens)
A881 ..	Additional ranges as required
	Heap and Solution Cyanide Detoxification:
M1	Water rinse
AC1 ...	Sulfite-air
AS1 ...	Chlorination
BI1	HP_x
	Seed and Fertilizer Cost List:
G61 ...	Seed, shrub, and fertilizer costs (26 screens)
	Macros:
GY1 ...	Spreadsheet print and clear macros

Worksheet Protection

HEAPREC uses three types of cells in the template; information, data entry, and calculation. Information cells contain data for the benefit of the user, such as a cost summary. Calculation cells hold equations for determining costs. Information and calculation cells do not regularly require modification by the user and are "protected" to inhibit inadvertent changing of data in these cells. Data entry cells that require input or modification by the user are "unprotected." If using a monochrome monitor the unprotected data entry cells will be **highlighted.** For color monitors the unprotected cells are a contrasting color. Both color and monochrome monitors allow easy identification of data entry cells.

If modification to a protected cell is required, such as modifying equations or changing given data, temporarily disable the protection on the entire template. Change the protection status with the **"/", Worksheet, Global, Protection,** and **Enable** or **Disable** keystrokes. If not modifying a protected cell's contents **LEAVE THE WORKSHEET PROTECTED.** NOTE: Some of the data entry and protected cells will initially contain **ERR,** which is a message indicating that an attempt was made to divide a numerical value by zero. The **ERR** messages are the result of clearing the spreadsheet of input data. When data entry is complete there should be no **ERR** messages in ranges with data entry.

Information Requirements

The general types of information needed to calculate a reclamation bond for cyanide heap leach facilities include:

(1) Method for detoxifying cyanide-bearing wastes;
(2) Contour map of sufficient scale depicting proposed disturbances (used primarily to determine haul distances and grades);
(3) Areas to be revegetated;
(4) Types of vegetation required;
(5) Types and sizes of structures requiring removal;
(6) Lengths and widths of road areas to be reclaimed, including pre- and post-road slopes (for volume estimates of material to be moved);
(7) Location of topsoil stockpiles;

(8) Reshaping or recontouring requirements for heaps, operating slope of heap and post-operating slope of heap (for volume estimates of material to be moved);

(9) Local availability of equipment for reclamation;

(10) Electrical power rates (utility or generated on-site);

(11) Labor rates;

(12) Equipment operating costs.

The primary source for this information should be the preproduction reclamation plan. A preproduction reclamation plan is generally a requirement for obtaining an operating permit. See appendix D for additional information and assistance in determining earthwork and revegetation related costs. For background data on cyanide detoxification methods, see appendix C.

GETTING STARTED

In order to run HEAPREC, the user must have a copy of Lotus 1-2-3 release 2.01 or newer installed on a computer. HEAPREC requires 512 kilobytes (KB) of main memory (RAM). Before proceeding, make a backup copy of HEAPREC on another diskette and/or write-protect the diskette containing the original HEAPREC file.

It is assumed that the operator is acquainted with the basic fundamentals of Lotus. If unfamiliar with Lotus, complete the Lotus tutorial before using HEAPREC. If working with a hard-disk system, consider creating a separate directory for HEAPREC and associated working files using the appropriate DOS commands.

To use HEAPREC, begin 1-2-3 as instructed in the Lotus manual. When at the initial blank spreadsheet screen, retrieve HEAPREC by pressing "/", move the menu pointer to File ("F") and press **ENTER**, then highlight Retrieve ("R") and press **ENTER**. The menu now contains the files specified in the current directory. If needed, change to the directory containing HEAPREC by pressing "ESC" twice, then specify the directory containing HEAPREC. When in the directory containing HEAPREC, highlight **HEAPREC.WK1** and press **ENTER** to enter the template. Press the **HOME** key to reorient to the upper left corner of the template (A1-F20), also referred to as the HOME SCREEN.

SUMMARY SECTION

The SUMMARY SECTION (A1..F120) includes six screens which synopsize the costs calculated for the bond. The screens in this section are the HOME SCREEN (A1..F20); BOND ESTIMATE COST SUMMARY SCREEN (A21..F40); INDIRECT RECLAMATION COST SUMMARY SCREEN (A41..F60); and the EARTHWORK AND REVEGETATION COST SUMMARY SCREENS, which include the SUBSOIL EARTHWORK COST SUMMARY SCREEN (A61..F80), TOPSOIL EARTHWORK COST SUMMARY SCREEN (A81..F100), and the SEEDING COST SUMMARY SCREEN (A101.. F120). Refer to the schematic of HEAPREC (fig. 1) for the relative location of these screens in the template.

HOME SCREEN (A1..F20)

The HOME SCREEN should be considered the reference point for the spreadsheet; pressing **HOME** when in the template will always bring you to this screen. The HOME SCREEN summarizes the necessary keystrokes required to conveniently move throughout the template one full screen at a time.

Input data: Enter a mine name or description in cell B8; use a unique name for each bond estimate. Cell B9, cost date, for accuracy all costs should be indexed to the same date, (i.e. January 1980 dollars are not equivalent to January 1991 dollars). The HOME SCREEN of the template is shown in figure 2.

If this is the initial bond estimation for a property, proceed directly to the EQUIPMENT AND LABOR OPERATING COST RANGE (G1..L60) using **<CTRL> RIGHT** arrow, after completing data entry on the HOME SCREEN.

NOTE: **CALC** in the bottom right-hand corner of figure 2 denotes that the template is set on manual calculation and only calculates values after the **F9** key is pressed. When a numerical value is entered requiring recalculation, **CALC** will appear at the bottom right corner of the screen. Press **F9** to update calculations. Automatic recalculation can be set by pressing '/', Worksheet, Global, Recalculation, and Automatic; however, because of size of the template, this may bog down the computer and increase data entry time.

BOND ESTIMATE COST SUMMARY SCREEN (A21..F40)

The BOND ESTIMATE COST SUMMARY SCREEN (fig. 3) sums all of the direct reclamation costs and indirect costs calculated in other portions of the template for a grand total bond amount shown in cell B40.

```
     A          B          C          D          E          F
1
2          **************************************************
3          * WELCOME TO HEAPREC - A TEMPLATE FOR HEAP LEACH *
4          *                                                *
5          *          RECLAMATION BOND ESTIMATION           *
6          **************************************************
7
8            MINE NAME: (PUT MINE NAME HERE)
9    DATE OF BOND COSTS: (DATE OF COSTS)
10        TODAY'S DATE: 24-Aug-91
11
12  ***REMEMBER:  Move throughout the template with the following
13                "COMMANDS":
14
15              <Page Down> - Down one full screen
16                <Page Up> - Up one full screen
17            <CTRL>[Right] - One full screen right
18             <CTRL>[Left] - One full screen left
19                   <Home> - Returns to this screen
20
                                                    CALC
```

Figure 2.—Home screen.

```
     A                    B          C          D          E          F
21   ---BOND ESTIMATE COST SUMMARY---
22   ********************************************************************************
23
24       RECLAMATION TASK            COST      RANGE TYPE
25   DIRECT BOND COSTS:
26    SUBSOIL EARTHWORK                 $0        A61 SUMMARY
27    TOPSOIL EARTHWORK                 $0        A81 SUMMARY
28    SEEDING                           $0       A101 SUMMARY
29    PLANTING TREES AND SHRUB          $0       A641 CALCULATION
30    STRUCTURE REMOVAL                 $0       A661 CALCULATION
31    LINER/SEDIMENT DISPOSAL           $0       A681 CALCULATION
32    CAPPING HEAP                      $0       A741 CALCULATION
33   DETOXIFICATION METHOD               0 (1=RINSE,2=SULF/AIR,3=CHLOR,4=HPx.)
34    HEAP DETOXIFICATION      0.000E+00 (M1-RINSE,AC1-SULF,AS1-Cl,BI1-HPx)
35   --------------------------------------------------------------------------------
36   TOTAL DIRECT COSTS        0.000E+00
37   ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
38   INDIRECT COSTS                    $0        A41 SUMMARY
39   ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
40   GRAND TOTAL BOND AMOUNT   0.000E+00
```

Figure 3.—Bond estimate cost summary screen.

NOTE: Due to formatting limitations on this screen, ****** will show in column B when costs are equal to or greater than $1 million. If ****** appear, reformat cells B26..B32 and B38 for scientific notation using LOTUS keystrokes "/", Range, Format, Scientific, and 3. If CALC appears in the bottom right-hand corner of the screen, press F9 to update the calculations.

Input data: The only input required is cell B33 which selects the appropriate costs for the detoxification method chosen. Enter 1 for FRESH WATER RINSE, 2 for SULFITE-AIR, 3 for CHLORINATION, or 4 for HYDROGEN PEROXIDE.

NOTE: With the exception of the HOME SCREEN and SEED LIST RANGE, the first row of each screen identifies the screen as well as how many screens are included in the range (row 21, figure 3).

INDIRECT RECLAMATION COST SUMMARY SCREEN (A41..F60)

The INDIRECT RECLAMATION COST SUMMARY SCREEN, as shown in figure 4, calculates and accounts for the cost of a regulatory agency contracting a third party to complete site reclamation. The mobilization cost is an assumed constant percentage of the total direct reclamation cost, modify if needed. The sales and use tax is based on sum of the total direct reclamation cost and all indirect costs excluding the reclamation management fee. The remaining indirect costs, contingency, profit and overhead, engineering redesign fee, and reclamation management fee are based on a percentage of the total direct reclamation cost. These percentages are calculated by HEAPREC, vary based on the total direct cost, and are founded on cost estimating principles. If modification of these percentages is required based on agency policy or based on actual experience, replace the equations in column C with the appropriate numerical expression using the LOTUS edit key (F2) after removing the worksheet protection ("/", Worksheet, Global, Protection, Disable). Do not modify the equations in column B. Remember to enable the worksheet protection ("/", Worksheet, Global, Protection, Enable) when equation editing is completed. See appendix D for additional information.

Input data: Enter the combined State sales and use tax rate in B50. No additional input required unless agency policy requires using a specific value or percentage.

EARTHWORK AND REVEGETATION COST SUMMARY SCREENS (A61..F120)

The EARTHWORK AND REVEGETATION COST SUMMARY SCREENS include a summary screen for SUBSOIL EARTHWORK (A61..F80), TOPSOIL EARTHWORK (A81..F100), and SEEDING (A101..F120). These three screens total the cost for reclamation tasks, categorize them into four areas—facilities, heaps, roads, and ponds—and also identify the upper left-hand corner of each task's first screen. No data input is required. The SUBSOIL EARTHWORK SCREEN is shown in figure 5; the other two screens are similar.

```
          A                    B          C          D          E          F
41   ---INDIRECT RECLAMATION COSTS (AS A FUNCTION OF DIRECT COSTS)---
42   ************************************************************************
43
44                              PERCENT      COST
45   MOBILIZATION                  3.00         $0
46   CONTINGENCY                   7.00         $0
47   PROFIT AND OVERHEAD           8.00         $0
48   ENGINEERING REDESIGN FEE      6.00         $0
49   RECLAMATION MGMT FEE          4.00         $0
50   SALES AND USE TAX             0.00         $0
51   -------------------------              ----------
52   TOTAL INDIRECT COST                          $0
53
54
55
56
57
58
59
60
                                                                        CALC
```

Figure 4.—Indirect reclamation cost summary screen.

```
          A                B          C          D          E          F
61   ---EARTHWORK AND REVEGETATION COST SUMMARY (1 of 3 screens)---
62   ********************************************************************************
63     SUBSOIL EARTHWORK
64
65          TASK            FACILITIES     HEAPS      ROADS      PONDS    RANGE
66   ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
67    SCRAPER - SUBSOIL            $0         $0         $0         $0     A121
68    WHEEL LOADER - SUBSOIL       $0         $0         $0         $0     A141
69    LOADER/TRUCK - SUBSOIL       $0         $0         $0         $0     A161
70    DOZER - SUBSOIL              $0         $0         $0         $0     A201
71    BACKHOE - SUBSOIL            $0         $0         $0         $0     A221
72    DOZER - RECONTOUR HEAPS     N/A         $0        N/A        N/A     A241
73    DOZER - GRADE LEVEL AREA     $0         $0         $0         $0     A261
74    DOZER - GRADE SLOPES         $0         $0         $0         $0     A281
75    DOZER - RIPPING              $0         $0         $0         $0     A301
76   ================================================================================
77    SUBSOIL SUBTOTAL COSTS       $0         $0         $0         $0
78
79    TOTAL SUBSOIL EARTHWORK      $0
80    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
                                                          CALC
```

Figure 5.—Subsoil earthwork cost summary screen.

EQUIPMENT AND LABOR OPERATING COST RANGE

The EQUIPMENT AND LABOR OPERATING COST RANGE (G1..L60) includes two screens for entering equipment operating cost data and one screen for entering labor rates. All equipment operating costs and labor rates used in the earthmoving and revegetation cost calculations are entered on these screens. Using the full screen commands, the beginning of this range can be readily accessed with **HOME** and then two **<CTRL> RIGHT** keystrokes.

EQUIPMENT SELECTION SCREENS (G1..L40)

Six different equipment types can be specified in EQUIPMENT SELECTION SCREENS (G1..L20) and (G21..L41), including dozer, wheel loader, scraper, truck, motor grader, and backhoe. Equipment selection is broken into four specific areas: facilities, heaps, roads, and ponds (fig. 6). Based on the reclamation tasks required, each equipment type may not be used. Use of multiple pieces of the same size equipment for completing a reclamation task are accounted for. A different size of equipment can be specified for completing tasks in each area (heaps, facilities, roads, ponds). However, two different sizes of equipment can not be specified for use in the same area (i.e., a D9S dozer and a D11U dozer can not be specified to recontour a heap; use either D9Ss or D11Us).

Some assistance in selecting equipment types, sizes, and operating costs are provided in EARTHWORK (appendix D). Popular sources for deriving equipment productivity and/or operating costs are:

(1) Caterpillar Tractor Company. Caterpillar Performance Handbook. Peoria, IL, 21st ed., 1990, 928 pp.

(2) Dataquest Inc. Cost Reference Guide for Construction Equipment. The Dun & Bradstreet Corp., San Jose, CA, 1990, 23 sections.

(3) Mahoney, W. D. (ed.). Construction Cost Data, Western Edition. R. S. Means Co., Inc., 1991, 502 pp.

(4) Mahoney, W. D. (ed.). Heavy Construction Cost Data, Western Edition. R. S. Means Co., Inc., 1991, 404 pp.

(5) Western Mine Engineering. Mining Cost Service. Spokane, WA, 1990.

(6) U.S. Forest Service (Dep. Agriculture). Cost Estimating Guide for Road Construction. Region 4, Div. Eng., June 1990, 53 pp.; available upon request from U.S. Forest Service, Intermountain Region, Ogden, UT.

Equipment operating cost and productivity information can also be obtained from local earthmoving contractors, mining companies, and actual reclamation projects.

Input data: Input data generic to all equipment include make-model, the data source used, and cost per hour to operate. Information in make-model and data source cells identify the data for future uses (i.e., justifying costs, bond updates, or future bond calculations). Equipment operating costs should not include profit or overhead, since this is included in the project's indirect cost calculation. Equipment operating costs should include ownership and overhaul costs and field repair and fuel expenses. The operating cost should also include

	G	H	I	J	K	L
1	EQUIPMENT SELECTION - DATA RANGE (1 of 2 screens)					
2	MOTOR GRADER	FACILITIES	HEAPS	ROADS	PONDS	
3	BLADE WIDTH	0	0	0	0	ft
4	MAKE/MODEL	0	0	0	0	
5	COST	$0.00	$0.00	$0.00	$0.00	per hr
6	DATA SOURCE	0	0	0	0	
7						
8	DOZER					
9	HORSEPOWER	0	0	0	0	hp
10	RIPPER WIDTH	0	0	0	0	ft
11	MAKE/MODEL	0	0	0	0	
12	COST	$0.00	$0.00	$0.00	$0.00	per hr
13	DATA SOURCE	0.00	0.00	0.00	0.00	
14						
15	WHEEL LOADER					
16	CAPACITY	0	0	0	0	cy
17	SPEED 2ND GEAR	0	0	0	0	mph
18	MAKE/MODEL	0	0	0	0	
19	COST	$0.00	$0.00	$0.00	$0.00	per hr
20	DATA SOURCE	0	0	0	0	
				CALC		

Figure 6.—Equipment selection screen.

the cost for all attachments being used for that task (i.e., rippers and U-blades for dozers). For costs, enter the numerical value only, the template is formatted to add the "$" sign.

MOTOR GRADER BLADE WIDTH, cells H3..K3, is the total width of the grader blade.

DOZER HORSEPOWER, cells H9..K9, is the flywheel-rated power of the engine.

DOZER RIPPER WIDTH, cells H10..K10, based on using a multi-shank ripper, is the distance between the centers of the dozer tracks. If using a single-shank ripper, enter the horizontal distance between rips (typically one-half the distance between the centers of the dozer tracks).

WHEEL LOADER CAPACITY, cells H16..K16, is the rated capacity (nominal heaped) of the loader bucket in cubic yards.

WHEEL LOADER SPEED 2D GEAR, cells H17..K17, is the speed in miles per hour (mph) the wheel loader will travel in 2d gear at the engine's rated performance. This speed should be used only for haul distances under 300 ft; consider using a higher speed for distances over 300 ft.

SCRAPER CAPACITY, cells H23..K23, is the rated capacity (heaped) of the scraper in cubic yards.

TRUCK CAPACITY, cells H29..K29, is the rate capacity (heaped) of the truck in cubic yards.

TRUCK SPEED, cells H30..K30, is the average speed, in miles per hour (mph), the truck travels at to and from the load and dump sites. (Determined by calculating the total round trip distance (ft) divided by the total of the travel time loaded and travel time unloaded (min), then convert to mph by dividing this quantity by 88 ft/min.)

BACKHOE-EXCAVATOR CAPACITY, cells H36..K36, is the rated capacity (heaped) of the bucket in cubic yards.

LABOR RATE SCREEN (G41..L60)

Seven labor classifications can be specified on the LABOR RATE SCREEN (G41..L60) (fig. 7). Labor rates should include the cost of burden and fringe (sick leave, vacation, insurance, retirement funds, payroll taxes, etc.), which typically range from 35% to 50% of the base wage rate. Labor rates should not include project profit or main office overhead costs since these costs are accounted for in the project's indirect cost calculation.

As in the equipment selection screen, labor is broken into four specific areas—heaps, ponds, roads, and facilities. If needed, labor rates can then be modified in each of these four areas (e.g., if the operator's wage scale is based on the size of equipment operated).

In most instances, State and/or Federal regulations will dictate what wage scale (e.g., Davis-Bacon) will be used for calculating reclamation performance bonds. If regulations do not require using a specific labor rate schedule, other sources for labor rates include:

(1) Mahoney, W. D. (ed.). Heavy Construction Cost Data, Western Edition. R. S. Means Co., Inc., 1991, 404 pp.

(2) Western Mine Engineering. Mining Cost Service. Spokane, WA, 1991.

	G	H	I	J	K	L
41	---LABOR RATES - DATA RANGE (1 of 1 screen)---					
42	**********					
43	LABOR RATES	FACILITIES	HEAPS	ROADS	PONDS	
44	~~~~~~~~~~					
45	GENERAL LABOR	$0.00	$0.00	$0.00	$0.00	per hr
46	DOZER OPERATOR	$0.00	$0.00	$0.00	$0.00	per hr
47	MOTOR GRADER OPERATOR	$0.00	$0.00	$0.00	$0.00	per hr
48	WHEEL LOADER OPERATOR	$0.00	$0.00	$0.00	$0.00	per hr
49	TRUCK DRIVER	$0.00	$0.00	$0.00	$0.00	per hr
50	SCRAPER OPERATOR	$0.00	$0.00	$0.00	$0.00	per hr
51	BACKHOE OPERATOR	$0.00	$0.00	$0.00	$0.00	per hr
52						
53						
54						
55						
56						
57						
58						
59						
60						

CALC

Figure 7.—Labor rate screen.

Input data: All input data is self-explanatory, the wage rates are in dollars per hour. Enter the numerical value only, the template is formatted to add the "$" sign. NOTE: If the wage scale for a labor classification is constant for all four areas use the LOTUS copy command to expedite data entry ("/", Copy, then specify the range to copy from, specify the range to copy to, and press ENTER).

EARTHWORK AND REVEGETATION COST CALCULATION SECTION

The EARTHWORK AND REVEGETATION COST CALCULATION SECTION (A121..F881) includes 25 ranges for determining costs for completing reclamation tasks. The ranges are roughly divided into eight types of reclamation activities (HEAPREC schematic, figure 1), SUBSOIL EARTHWORK (A121..F240), OTHER DOZER APPLICATIONS (A241..F320), TOPSOIL APPLICATION (A321..F420), TOPSOIL GRADING (A421..F480), REVEGETATION (A481..F660), STRUCTURE DEMOLITION (A661..F680), LINER DISPOSAL (A681..F740), and CAPPING HEAP (A741..F881). **Before proceeding with this section, complete data entry in the EQUIPMENT AND LABOR OPERATING COST RANGE (G1..L60).** The beginning of this section can be readily accessed with a **HOME** and 6 **PAGE DOWN** keystrokes.

The primary source of information for completing data input in this section should be site reclamation plans and data supporting these plans. The EQUIPMENT SELECTION SECTION (appendix D) provides some assistance in choosing equipment types for performing these tasks (when to use a scraper instead of a dozer, etc.). The COST EQUATION SECTION (appendix E) includes a description of all the equipment productivity and cost equations used. The equation descriptions are an invaluable aid to a user who intends to customize the template, modify an equation, or has questions about a cost computation.

Costs can be compared for completing a task with one type of equipment versus another; however, be sure to zero out input data in the range not to be used when finished with the comparison. In most instances, all 25 of the calculation ranges will not be used. If a range is not going to be used, do not enter any input data into that range.

SUBSOIL EARTHWORK (A121..F240)

There are five ranges for calculating costs related to subsoil earthwork tasks: SCRAPER, WHEEL LOADER, WHEEL LOADER-TRUCK, DOZER, and BACKHOE. Additional information can be found in the SUBSOIL EARTHMOVING SECTION (appendix D). An example screen is shown in figure 8. Each range can be used to account for tasks performed in one or all four areas—facilities, heaps, roads, and ponds.

Data input and calculation cells for each range are identified below. Refer to the COST EQUATION SECTION (appendix E), if intending to modify any equations.

```
        A                          B          C          D          E          F
121   ---SCRAPER - SUBSOIL EARTHWORK (1 of 1 screen)---
122   ************************************************************************
123                              FACILITIES     HEAPS      ROADS      PONDS
124   ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
125     **HAUL DISTANCE                   0          0          0          0 ft
126     **MATERIAL TO MOVE                0          0          0          0 cyd
127
128
129     SCRAPER TYPE                      0          0          0          0
130     CAPACITY                          0          0          0          0 cy
131     OPERATING COST                $0.00      $0.00      $0.00      $0.00 per hr
132     LABOR COST                    $0.00      $0.00      $0.00      $0.00 per hr
133     PRODUCTION                        0          0          0          0 cy/hr
134     TOTAL TIME AT 80 PCT EFF        ERR        ERR        ERR        ERR hrs
135   ========================================================================
136     SCRAPER-SUBSOIL COSTS            $0         $0         $0         $0
137
138
139
140
                                                  CALC
```

Figure 8.—Scraper, subsoil earthwork screen.

REMEMBER: Move the cursor to the **highlighted** cells for data input and that information and calculation cells are "protected" to inhibit inadvertent modification.

SCRAPER - SUBSOIL EARTHWORK (A121..F140): In cells B125..E125, enter the average one-way haul distance (ft) the subsoil will be transported. In cells B126..E126, enter the amount of subsoil (yd^3) to be moved. The scraper type, capacity, and equipment and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Rows 133, 134, and 136 contain calculation cells.

WHEEL LOADER - SUBSOIL EARTHWORK (A141..F160): In cells B145..E145, enter the average one-way haul distance (ft) the subsoil will be transported. In cells B146..E146, enter the amount of subsoil (yd^3) to be moved. The loader type, capacity, haul speed, and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Row 154, LOAD, DUMP, MANEUVER TIME is an assumed constant, modify if site conditions warrant it. Rows 155-158 contain calculation cells.

WHEEL LOADER-TRUCK - SUBSOIL EARTHWORK (A161..F200): In cells B165..E165, enter the average one-way haul distance (ft) the subsoil will be transported. In cells B166..E166, enter the amount of subsoil (yd^3) to be moved. The wheel loader and truck types, capacities, and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Row 175, MANEUVER, DUMP TIME and row 187, LOAD, DUMP, MANEUVER TIME are assumed constants; modify if site conditions warrant it. Rows 191-197 contain calculation cells.

DOZER - SUBSOIL EARTHWORK (A201-F220): In cells B205..E205, enter the average one-way distance (ft) the subsoil will be pushed. In cells B206..E206, enter the amount of subsoil (yd^3) to be moved. In cells B207..E207, enter the positive or negative grade (%) in the push direction. In cells B215..E215, an operator efficiency factor of 0.75 is given for an operator with average skill; enter 1.00 for an excellent or 0.60 for a poorly skilled operator. In cells B216..E216, a job efficiency factor of 0.83 is given for efficient equipment operation of 50 min/h; enter 0.67 if efficient equipment utilization is 40 min/h. The dozer type, flywheel horsepower rating, and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Rows 213-214 and 217-218 contain calculation cells and can be used for comparing optimum dozer productivity versus estimated dozer productivity.

BACKHOE-EXCAVATOR - SUBSOIL EARTHWORK (A221..F240): In cells B225..E225, enter the volume (yd^3) of subsoil to be excavated. The backhoe-excavator type, bucket capacity, and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Row 230, BUCKET PAYLOAD and row 231, LOAD, SWING, DUMP, SWING TIME are assumed constants; modify if site conditions warrant. Rows 235 and 236 contain calculation cells.

OTHER DOZER APPLICATIONS (A241..F320)

Four ranges for calculating costs related to dozer subsoil earthwork, not accounted for in the previous section, are: RECONTOUR HEAPS, GRADING LEVEL AREAS, GRADING SLOPES, AND RIPPING. An example screen is shown in figure 9. Using full page screen commands, the beginning of this section is located 12 PAGE DOWN keystrokes below the HOME SCREEN or press the LOTUS "GO TO" command (F5), enter A241 at the prompt, then press ENTER.

Data input and calculation cells for each range are identified below. Refer to the COST EQUATION SECTION (appendix E) if you intend to modify any equations. REMEMBER: Move the cursor to the highlighted cells for data input and that information and calculation cells are "protected" to inhibit inadvertent modification.

DOZER - RECONTOUR HEAPS (A241..F260): Costs for recontouring up to four pads can be accounted for in this screen. In cells B245..E245, enter the perimeter distance (ft) along the crest where the heap side slopes and heap top meet. In cells B246..E246, enter the average slope angle of the heap side slopes, in positive degrees, prior to reclamation. In cells B247..E247, enter the average reclaimed heap side slope angle, in positive degrees. In cells B248..E248, enter the heap height (ft) prior to reclamation. In cells B255..E255, an operator efficiency factor of 0.75 is given for an operator with average skill; enter 1.00 for an excellent or 0.60 for a poorly skilled operator. In cells B256..E256, a job efficiency factor of 0.83 is given for efficient equipment operation of 50 min/h; enter 0.67 if efficient equipment utilization is 40 min/h. The dozer type, flywheel horsepower rating, and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Rows 249, 250, 257, and 258 contain calculation cells.

DOZER - GRADING LEVEL AREAS, SUBSOIL (A261..F280): In cells B265..E265, enter the level area (acres) of subsoil to be graded. In cells B266..E266, an operator efficiency factor of 0.75 is given for an operator with average skill; enter 1.00 for an excellent or 0.60 for a poorly skilled operator. In cells B267..E267, a job efficiency factor of 0.83 is given for efficient equipment operation of 50 min/h; enter 0.67 if efficient equipment utilization is 40 min/h. In cells B268..E268, enter the effective graded width per pass (75% to 90% of the dozer blade overall width). The dozer type and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Row 269, AVERAGE SPEED; row 270, AVERAGE PASS LENGTH; and row 271, MANEUVER TIME are assumed constants; modify if site conditions warrant it. Rows 274, 275, and 278 contain calculation cells.

DOZER - GRADING SLOPES, SUBSOIL (A281..F300): In cells B283..E285, enter the distance (ft) along the slope to be graded. In cells B286..E286, enter the width (ft) of the slope to be graded. In cells B289..E289, enter the effective graded width per pass (75% to 90% of the dozer blade overall width). In cells B296..E296, an operator efficiency factor of 0.75 is given for an operator with average skill; enter 1.00 for an excellent or 0.60 for a poorly skilled operator. In cells

	A	B	C	D	E	F
241	---DOZER - RECONTOUR HEAPS (1 of 1 screen)---					
242	**********					
243		PAD 1	PAD 2	PAD 3	PAD 4	
244	~~~~~~~~~~					
245	**HEAP CREST DISTANCE	0	0	0	0	ft
246	**HEAP SLOPE ANGLE (+)	0	0	0	0	degrees
247	**RECLAIMED ANGLE (+)	0	0	0	0	degrees
248	**HEAP HEIGHT	0	0	0	0	ft
249	MATERIAL TO MOVE	ERR	ERR	ERR	ERR	cy
250	PUSH DISTANCE	ERR	ERR	ERR	ERR	ft
251	DOZER HORSEPOWER	0	0	0	0	hp
252	DOZER TYPE	0	0	0	0	
253	OPERATING COST	$0.00	$0.00	$0.00	$0.00	per hr
254	LABOR COST	$0.00	$0.00	$0.00	$0.00	per hr
255	**OPERATOR FACTOR	0.75	0.75	0.75	0.75	
256	**JOB EFFICIENCY FACTOR	0.83	0.83	0.83	0.83	
257	PRODUCTION	ERR	ERR	ERR	ERR	cy/hr
258	TOTAL TIME	ERR	ERR	ERR	ERR	hrs
259	==========					
260	DOZER-RECON HEAP COSTS	$0	$0	$0	$0	

Figure 9.—Dozer, recontour heaps screen.

B297..E297, a job efficiency factor of 0.83 is given for efficient equipment operation of 50 min/h; enter 0.67 if efficient equipment utilization is 40 min/h. The dozer type and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Row 291, AVERAGE SPEED and row 292, MANEUVER TIME are assumed constants; modify if site conditions warrant it. Rows 287, 294, 295, and 296 contain calculation cells.

DOZER - RIPPING SUBSOIL (A301..F320): In cells B305..E305, enter the area (acres) of subsoil to be ripped with a dozer. In cells B315..E315, an operator efficiency factor of 0.75 is given for an operator with average skill; enter 1.00 for an excellent or 0.60 for a poorly skilled operator. In cells B316..E316, a job efficiency factor of 0.83 is given for efficient equipment operation of 50 min/h; enter 0.67 if efficient equipment utilization is 40 min/h. The dozer type, overall ripper width, and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Row 308, AVERAGE SPEED; row 309, AVERAGE PASS LENGTH; and row 310, MANEUVER TIME are assumed constants; modify if site conditions warrant it. Rows 303, 304, and 307 contain calculation cells.

TOPSOIL APPLICATION (A321..F420)

There are four ranges for calculating costs related to hauling and applying topsoil—DOZER, SCRAPER, WHEEL LOADER, and WHEEL LOADER-TRUCK. Background information on this range can be found in the TOPSOIL APPLICATION SECTION (appendix D). An example screen is shown in figure 10. Each range can be used to account for costs to transport topsoil from stockpiles to one or all four areas (facilities, ponds, roads, heaps) where the topsoil will be reapplied. The beginning of this section can be located by pressing the LOTUS "GO TO" command (F5); enter A321 at the prompt, then press ENTER. NOTE: If wheel loaders and wheel loaders-trucks are used to transport topsoil, remember to account for final topsoil grading costs with the TOPSOIL GRADING ranges.

Data input and calculation cells for each range are identified below. Refer to the COST EQUATION SECTION (appendix E) if intending to modify any equations. **REMEMBER:** Move the cursor to the **highlighted** cells for data input and that information and calculation cells are "protected" to inhibit inadvertent modification.

DOZER - TOPSOIL APPLICATION (A321..F340): Enter the average distance (ft) from the topsoil stockpile to the area being topsoiled in cells B325..E325. Enter the amount of area (acres) to be topsoiled in cells B326..E326. In cells B327..E327, enter the topsoil depth (ft) to be spread over each area. Enter the average grade (%) expected, positive or negative, in the haul direction. The dozer type, flywheel horsepower, and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Row 332, AVERAGE DOZER SPEED is an assumed constant; modify if site conditions warrant it. In cells B335..E335, an operator efficiency factor of 0.75 is given for an operator with average skill; enter 1.00 for an excellent or 0.60 for a poorly skilled operator. In cells B336..E336, a job efficiency factor of 0.83 is given for efficient equipment operation of 50 min/h; enter 0.67 if efficient equipment utilization is 40 min/h. Rows 337 and 338 contain calculation cells.

	A	B	C	D	E	F
321	---DOZER - TOPSOIL APPLICATION (1 of 1 screen)---					
322	**********					
323		FACILITIES	HEAPS	ROADS	PONDS	
324	~~~~~~~~~~					
325	**HAUL DISTANCE	0	0	0	0	ft
326	**ACRES	0	0	0	0	ac
327	**TOPSOIL DEPTH	0	0	0	0	ft
328	**PCT GRADE	0	0	0	0	%
329						
330	DOZER HORSEPOWER	0	0	0	0	hp
331	DOZER TYPE	0	0	0	0	
332	AVERAGE DOZER SPEED	2	2	2	2	mph
333	OPERATING COST	$0.00	$0.00	$0.00	$0.00	per hr
334	LABOR	$0.00	$0.00	$0.00	$0.00	per hr
335	**OPERATOR FACTOR	0.75	0.75	0.75	0.75	
336	**JOB EFFICIENCY FACTOR	0.83	0.83	0.83	0.83	
337	PRODUCTION	0	0	0	0	cy/hr
338	TOTAL TIME	ERR	ERR	ERR	ERR	hrs
339	==========					
340	DOZER-TOPSOIL APP COSTS	$0	$0	$0	$0	

Figure 10.—Dozer, topsoil application screen.

SCRAPER - TOPSOIL APPLICATION (A341..F360): Enter the average one-way distance (ft) from the topsoil stockpile to the area being topsoiled in cells B345..E345. Enter the amount of area (acres) to be topsoiled in cells B346..E346. In cells B347..E347, enter the average topsoil depth (ft) to be spread over each area. The scraper type, capacity, and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Rows 353 and 354 contain calculation cells.

WHEEL LOADER - TOPSOIL APPLICATION (A361..F380): Enter the average one-way distance (ft) from the topsoil stockpile to the area being topsoiled in cells B365..E365. Enter the amount of area (acres) to be topsoiled in cells B366..E366. In cells B367..E367, enter the average topsoil depth (ft) to be spread over each area. The wheel loader type, bucket capacity, haul speed, and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Row 374 is an assumed constant; modify if site conditions warrant it. Rows 375 to 378 contain calculation cells.

WHEEL LOADER-TRUCK - TOPSOIL APPLICATION (A381..F400): Enter the average one-way distance (ft) from the topsoil stockpile to the area being topsoiled in cells B385..E385. Enter the amount of area (acres) to be topsoiled in cells B386..E386. In cells B387..E387, enter the average topsoil depth (ft) to be spread over each area. The wheel loader and truck types, capacities, and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Row 397, MANEUVER, DUMP TIME and row 407, LOAD, DUMP, MANEUVER TIME are assumed constants; modify if site conditions warrant. Rows 411-417 contain calculation cells.

TOPSOIL GRADING (A421..F480)

There are three ranges for calculating costs related to final grading of topsoil: DOZER - GRADING LEVEL AREAS, DOZER - GRADING SLOPES, and MOTOR GRADER. Topsoil grading should be considered if the topsoil was transported to the topsoiled area by wheel loaders or a wheel loader-truck combination. An example screen is shown in figure 11. The beginning of this section can be located by pressing the LOTUS "GO TO" command (F5); enter A421 at the prompt, then press ENTER.

Data input and calculation cells for each range are identified below. Refer to the COST EQUATION SECTION (appendix E) if intending to modify any equations.

REMEMBER: Move the cursor to the **highlighted** cells for data input and that information and calculation cells are "protected" to inhibit inadvertent modification.

DOZER - GRADING LEVEL AREAS, TOPSOIL (A421..F440): In cells B425..E425 enter the amount of topsoiled level area (acres) to be graded. In cells B428..E428 enter the effective graded width per pass (75% to 90% of the dozer blade overall width). The dozer type and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Row 429, AVERAGE SPEED; row 430, AVERAGE PASS LENGTH; and row 431, MANEUVER TIME are assumed constants; modify if site conditions warrant it. In cells B436..E436, an operator efficiency factor of 0.75 is given for an operator with average skill; enter 1.00 for an excellent or 0.60 for a poorly skilled operator. In cells B437..E437, a job efficiency factor of 0.83 is given for efficient equipment operation of 50 min/h; enter 0.67 if efficient equipment utilization is 40 min/h. Rows 434, 435, and 438 contain calculation cells.

DOZER - GRADING SLOPES, TOPSOIL (A441..F460): In cells B445..E445 enter the distance (ft) along the topsoiled slope to be graded. In cells B446..E446, enter the width (ft) of the topsoiled slope to be graded. In cells B449..E449, enter the effective graded width per pass (75% to 90% of the dozer blade overall width). The dozer type and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Row 450, AVERAGE SPEED and row 451, MANEUVER TIME are assumed constants; modify if site conditions warrant it. In cells B456..E456, an operator efficiency factor of 0.75 is given for an operator with average skill; enter 1.00 for an excellent or 0.60 for a poorly skilled operator. In cells B457..E457, a job efficiency factor of 0.83 is given for efficient equipment operation of 50 min/h; enter 0.67 if efficient equipment utilization is 40 min/h. Rows 447, 454, 455, and 458 contain calculation cells.

MOTOR GRADER - GRADING TOPSOIL (A461..F480): Enter the area (acres) to be graded in cells B465..E465. Grader type, blade width, and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Row 470, MANEUVER TIME; row 471, AVERAGE PASS; row 473, AVERAGE SPEED; and row 473, NUMBER OF PASSES OVER AREA are assumed constants; modify if site conditions warrant it. Rows 469, 476, 477, and 478 contain calculation cells.

	A	B	C	D	E	F
421	---DOZER - GRADING LEVEL AREAS, TOPSOIL (1 of 1 screen)---					
422	**********	**********	**********	**********	**********	
423		FACILITIES	HEAPS	ROADS	PONDS	
424	~~~~~~~~~~	~~~~~~~~~~	~~~~~~~~~~	~~~~~~~~~~	~~~~~~~~~~	
425	**ACREAGE	0	0	0	0	ac
426						
427	DOZER TYPE	0	0	0	0	
428	**GRADED WIDTH	0	0	0	0	ft
429	AVERAGE SPEED	1	1	1	1	mph
430	AVERAGE PASS LENGTH	500	500	500	500	ft
431	MANEUVER TIME	0.25	0.25	0.25	0.25	min
432	OPERATING COST	$0.00	$0.00	$0.00	$0.00	per hr
433	LABOR COST	$0.00	$0.00	$0.00	$0.00	per hr
434	TRAVEL DISTANCE	0	0	0	0	ft
435	NUMBER OF PASSES	0	0	0	0	passes
436	**OPERATOR FACTOR	0.75	0.75	0.75	0.75	
437	**JOB EFFICIENCY FACTOR	0.83	0.83	0.83	0.83	
438	TOTAL TIME	0	0	0	0	hrs
439	==========	==========	==========	==========	==========	
440	DOZER-GRADE LEVEL COSTS	$0	$0	$0	$0	

Figure 11.—Dozer, grading level areas, topsoil screen.

REVEGETATION (A481..F660)

There are six ranges in this section for calculating costs related to revegetating areas: SEED AND FERTILIZER SELECTION, MULCH, SEED AND FERTILIZER APPLICATION, CRIMPING, EROSION CONTROL BLANKETS, and TREES AND SHRUBS. Background information on this section is located in the REVEGETATION SECTION (appendix D). The beginning of this template section can be located by pressing the LOTUS "GO TO" command (**F5**), enter A481 at the prompt, then press **ENTER**.

Because each of these ranges is somewhat unique, an example screen from each range is presented. Refer to the COST EQUATION SECTION (appendix E) if intending to modify any equations. **REMEMBER:** Move the cursor to the **highlighted** cells for data input and that information and calculation cells are "protected" to inhibit inadvertent modification.

SEED AND FERTILIZER, MIX #1-4 (A481..F560): This range calculates the cost for seeds and fertilizer on four screens, one for each area (i.e., facilities, heaps, roads, and ponds, [fig. 12]). Enter the area (acres) to be covered with seed and fertilizer in cells B482, B502, B522, and B542 of the appropriate screen. Specify the seed type and fertilizer type in column A using one of the following methods: (1) enter the seed and fertilizer type in column A by typing the name exactly as it is spelled in the SEED AND FERTILIZER COST LIST (G61..L600) or (2) with the cursor in the position where the user wants the data entered, select the seed or fertilizer type one at a time from the SEED AND FERTILIZER COST LIST (G61..L600) using the following keystrokes: "/", Copy, **<Esc>**, **<Ctrl> RIGHT**, then **highlight** the selection in column G only, and press **ENTER** twice. If a particular seed is not in the list, go to ADDITIONAL SEED MIXES (G497) and enter the seed name in column G and pure live seed cost per pound in column H. Then select the seed type using one of the above methods. In column B, enter the seed application rate in pure live seed (lb/acre) and fertilizer rate (lb/acre). If the seeding mix is the same for all areas, use the LOTUS copy function to copy data from columns A and B of one screen to the next.

MULCH (A561..F580): Enter the total area (acres) to be mulched in cells B565..E565 (fig. 13). Specify the application method in cells B568..E568. The APPLICATION RATE, row 567 and MULCH COST are assumed constants; modify if reclamation plan specifies a different mulching rate and/or if the expected cost of mulch delivered to the site is different. The application cost in cells B577 and B578 should also be modified if they are not applicable. Rows 569 and 573 contain calculation cells.

SEEDING AND FERTILIZER APPLICATION (A581..F600): Determine the method of seed and fertilizer application and specify the amount of area (acres) to be covered with each method in the appropriate cells of row 587 and/or row 593 (fig. 14). The UNIT OPERATION COST, rows 585 and 594 are assumed constants; modify if needed. The dry broadcast application cost is based on one operator with a cyclone spreader mounted on a 4-wheel drive, all-terrain vehicle with a

```
          A                    B          C          D          E          F
481   ---SEED AND FERTILIZER, MIX #1, FACILITIES (1 of 4 screens)---
482   **ACRES                          0 ac
483                              APPL.      COST       COST
484   SEED TYPE                lbs/acre      $/lb     $/acre
485   NONE                          0.0     $0.00      $0.00
486   NONE                          0.0     $0.00      $0.00
487   NONE                          0.0     $0.00      $0.00
488   NONE                          0.0     $0.00      $0.00
489   NONE                          0.0     $0.00      $0.00
490   NONE                          0.0     $0.00      $0.00
491   NONE                          0.0     $0.00      $0.00
492   FERTILIZER TYPE
493   NONE                            0     $0.00      $0.00
494   NONE                            0     $0.00      $0.00
495   NONE                            0     $0.00      $0.00
496   NONE                            0     $0.00      $0.00
497   NONE                            0     $0.00      $0.00
498   ------------------------------------------------------------------------
499   SEED COST                  $0.00
500   FERTILIZER COST            $0.00
```

Figure 12.—Seed and fertilizer screen.

```
          A                    B          C          D          E          F
561   ---MULCH (1 of 1 screen)---
562   ************************************************************************
563                              FACILITIES     HEAPS      ROADS      PONDS
564   ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
565   **ACRES                           0          0          0          0 ac
566
567   APPLICATION RATE                  2          2          2          2 st/ac
568   **TYPE (SEE BELOW)          M          H          H          H
569   APPLICATION COST                $50       $100       $100       $100
570
571   MULCH COST                      $70        $70        $70        $70 per st
572   ========================================================================
573
574   MULCH COST                       $0         $0         $0         $0
575
576   APPLICATION TYPE           COST/ACRE
577   ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
578   H=HAND BROADCAST                $100
579   M=MACHINE DRY BROADCAST          $50
580   W=HYDROMULCHED             INCLUDED ELSEWHERE
```

Figure 13.—Mulch screen.

	A	B	C	D	E	F
581	---SEEDING AND FERTILIZER APPLICATION (1 of 1 screen)---					
582	**********					
583		FACILITIES	HEAPS	ROADS	PONDS	
584	~~~~~~~~~~					
585	DRY BROADCAST APPL.					
586	----------					
587	**ACRES	0	0	0	0	ac
588	**UNIT OPERATION COST	$300	$300	$300	$300	per ac
589						
590						
591	WET BROADCAST APPL.					
592	----------					
593	**ACRES	0	0	0	0	ac
594	**UNIT OPERATION COST	$500	$500	$500	$500	per ac
595	==========					
596	SEEDING AND FERT. COST	$0	$0	$0	$0	
597						
598						
599						
600						

Figure 14.—Seeding and fertilizer application screen.

drag. The wet broadcast application cost is based on two operators using hydroseeding-hydromulching equipment.

DOZER-TRACKING SLOPES FOR TEMPORARY EROSION CONTROL (A601..F620): Tracking slopes with a dozer, commonly referred to as crimping, is usually done on areas just seeded for both erosion control as well as for creating a water catchment-supply for the seeds. In cells B605..E605, enter the length (ft) of slope to be crimped (fig. 15). In cells B606..E606, enter the width (ft) of the slope to be crimped. Enter the width (ft) of one dozer track in cells B608..E608. The dozer type and operating costs are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Row 509, AVERAGE SPEED and row 611, MANEUVER TIME are assumed constants; modify if site conditions warrant it. In cells B616..E616, an operator efficiency factor of 0.75 is given for an operator with average skill; enter 1.00 for an excellent or 0.60 for a poorly skilled operator. In cells B617..E617, a job efficiency factor of 1.0 is given for efficient equipment operation of 60 min/h; enter 0.83 if efficient equipment utilization is 50 min/h. Rows 606, 610, 614, 615, and 618 contain calculation cells.

EROSION CONTROL BLANKETS (A621..F640): To determine the estimated installed cost for erosion control blankets, enter the area (acres) to be covered in cells B624..E624 (fig. 16). Row 627 contains the estimated installed cost of this material; modify if needed.

PLANTING TREES AND SHRUBS (A641..F660): This range (fig. 17) accounts for the cost of transplanting trees and shrubs. Because of the cost variability due to locality, transplant size, and quantities planted, no costs are provided. Costs for trees and shrubs planted as seeds should be accounted for in the SEED AND FERTILIZER SECTION (A481..F560). If cost information is available, enter tree and/or shrub descriptions in column B, enter the total number of to be transplanted in column C, and enter the cost per transplant in column D. A list of tree varieties is provided in the TREE RANGE (G551..L582) of the SEED AND FERTILIZER COSTS.

STRUCTURE DEMOLITION (A661..F680)

There is only one range for calculating costs related to removing structures from the site (fig. 18). The types of buildings and structures at heap leach operations vary depending on remoteness, climate, project size, and project length. Due to this variability, the user is required to determine each structure's removal cost. In many instances, removal cost may equal the salvage value of the item; therefore, no costs should be calculated. If buildings are constructed on private lands (e.g. patented claims or millsites), they may not require removal. Costs can be calculated using: Mahoney, W. D. (ed.). Construction Cost Data, Western Edition. R. S. Means Co., Inc., 1991, 502 pp. For additional information see the STRUCTURE REMOVAL SECTION (appendix D). The beginning of this template section can be located by pressing the

```
          A                    B          C          D          E          F
601   ---DOZER-TRACKING SLOPES FOR TEMPORARY EROSION CONTROL (1 of 1 screen)--
602   ************************************************************************
603                          FACILITIES     HEAPS      ROADS      PONDS
604    **SLOPE LENGTH                 0         0          0          0 ft
605    **SLOPE WIDTH                  0         0          0          0 ft
606    SLOPE AREA                     0         0          0          0 ac
607    DOZER TYPE                     0         0          0          0
608    **TRACK WIDTH                  0         0          0          0 ft
609    AVERAGE SPEED                  1         1          1          1 mph
610    AVERAGE PASS LENGTH            0         0          0          0 ft
611    MANEUVER TIME               0.25      0.25       0.25       0.25 min
612    OPERATING COST             $0.00     $0.00      $0.00      $0.00 per hr
613    LABOR COST                 $0.00     $0.00      $0.00      $0.00 per hr
614    TRAVEL DISTANCE              ERR       ERR        ERR        ERR ft
615    NUMBER OF PASSES             ERR       ERR        ERR        ERR passes
616    **OPERATOR FACTOR           0.75      0.75       0.75       0.75
617    **JOB EFFICIENCY FACTOR        1         1          1          1
618    TOTAL TIME                   ERR       ERR        ERR        ERR hrs
619   ========================================================================
620    DOZER-TRACK SLOPES COSTS      $0        $0         $0         $0
```

Figure 15.—Dozer-tracking slopes screen.

```
          A                    B          C          D          E          F
621    ---EROSION CONTROL BLANKETS (1 of 1 screen)---
622   ************************************************************************
623                          FACILITIES     HEAPS      ROADS      PONDS
624    **ACRES                        0         0          0          0 ac
625
626   ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
627    UNIT INSTALLED COST        $1.00     $1.00      $1.00      $1.00 per syd
628      source:R4-USFS, 1990
629
630
631
632
633
634
635
636
637
638
639   ========================================================================
640    EROSION CNTRL BLNKT COSTS     $0        $0         $0         $0
```

Figure 16.—Erosion control blankets screen.

```
          A                B          C          D          E          F
641    ---PLANTING TREES AND SHRUBS (1 of 1 screen)---
642    ************************************************************************
643                                          COST       COST
644     TYPE                        NUMBER   $/tree     $/type
645    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
646                    0          0        $0.00      $0.00
647                    0          0        $0.00      $0.00
648                    0          0        $0.00      $0.00
649                    0          0        $0.00      $0.00
650                    0          0        $0.00      $0.00
651                    0          0        $0.00      $0.00
652                    0          0        $0.00      $0.00
653                    0          0        $0.00      $0.00
654                    0          0        $0.00      $0.00
655                    0          0        $0.00      $0.00
656                    0          0        $0.00      $0.00
657    ========================================================================
658     TREE AND SHRUB COSTS          $0
659
660
```

Figure 17.—Planting trees and shrubs screen.

```
          A                B          C          D          E          F
661    ---STRUCTURE REMOVAL (1 of 1 screen)---
662    ************************************************************************
663                          ON-SITE    SOURCE   OFF-SITE    SOURCE
664    ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
665     **PROCESS PLANT BUILDING      $0         0          $0         0
666     **OFFICE BUILDING             $0         0          $0         0
667     **EQUIPMENT                   $0         0          $0         0
668     **TRAILERS                    $0         0          $0         0
669     **FOUNDATIONS                 $0         0          $0         0
670     **PIPELINES                   $0         0          $0         0
671     **POWERLINES                  $0         0          $0         0
672     **TELEPHONE LINES             $0         0          $0         0
673     **FUEL STORAGE                $0         0          $0         0
674     **OTHER                       $0         0          $0         0
675    ------------------------------------------------------------------------
676     SUBTOTALS                     $0                    $0
677    ========================================================================
678     TOTAL REMOVAL COST            $0
679
680
```

Figure 18.—Structure removal screen.

LOTUS "GO TO" command (F5), enter A661 at the prompt, then press ENTER.

STRUCTURE REMOVAL (A661..F680): All costs must be calculated by the user. There is an option to specify whether the items are in the immediate vicinity of the heap leach operation (on-site) or structures related to the operation but located offsite.

LINER DISPOSAL (A681..F740)

Costs related to plastic liner and sediment disposal are calculated in one range containing three screens. For background information on this topic, read the POND LINER REMOVAL AND DISPOSAL SECTION (appendix D). The first screen of this range is shown in figure 19. The beginning of this template section can be located by pressing the LOTUS "GO TO" command (F5); enter A681 at the prompt, then press ENTER.

PLASTIC POND LINER AND POND SEDIMENT DISPOSAL (A681..F740): In cell B685, specify whether the liner is going to be buried in place (bury) or disposed of offsite (remove). In cells B687..B689, enter the corresponding amounts of synthetic liner, in thousands of ft^2, to be disposed. If multiple synthetic liners are used, enter the area of one liner for each pond only. In cells E687..E689, specify the liner thickness. If multiple synthetic liners are used, specify the combined thicknesses of the synthetic liners for each pond. In cell B692, specify whether the sediment is going to be buried in place (bury) or disposed of offsite (remove). If the sediment is to be buried in place, it is assumed that it will be mixed with cement; have the remaining liner folded over, then buried with soil. In cell B693, enter the total amount of sediment (st) accumulated in the ponds (assume an accumulated sediment thickness in each of the barren and pregnant ponds of 1.5 ft; multiply this thickness by the total surface area of the barren and pregnant ponds (ft^2), and divide this quantity by an assumed sludge density of 20 ft^3/st). If the sediment and/or liner is to be disposed of, enter the one-way haul distance (miles) to the disposal site in B694. Enter the disposal fee ($/st) in B695. Cell B696 contains an assumed sediment density of 20 ft^3/st; change if warranted. Screen 2 (A701..F720) contains the assumptions for burying the liner and/or sediment in place. B703, B704, and B706 are assumed constants; modify if warranted. Cell B705 contains an equation. Screen 3 (A721..F740) includes the assumptions and calculations for offsite disposal of the sediment and/or liner. Cells B723, backhoe capacity; B731 and B732, backhoe equipment and labor operating costs; and B733, general labor cost are specified in the EQUIPMENT AND LABOR OPERATING COST RANGE. Rows 724, 728, and 729 are assumed con-stants; modify if site conditions warrant it. Rows 725, 726, 727 and 730 contain calculation cells.

CAPPING HEAP (A741..F880)

Costs related to capping a heap are calculated in one range containing seven screens. Do not automatically include the costs calculated in this range unless regulations require a cap over the heap(s). The primary assumption should be that the heaps will be detoxified to meet cyanide standards and will not require a cap. Costs are calculated for a cap comprised of a low permeability soil-clay liner covered with a layer of crushed rock to promote drainage and protect the soil-clay liner. For background information on this topic, read the CAPPING HEAPS SECTION (appendix D).

The first screen of this range is shown in figure 20. The beginning of this template section can be located by pressing the LOTUS "GO TO" command (F5); enter A741 at the prompt, then press ENTER.

CAPPING HEAP (A741..F880): There are a total of seven data entry cells in these seven screens. The remaining cells are self-explanatory and contain information specified in the EQUIPMENT AND LABOR OPERATING COST RANGE, calculations, or assumed constants that should be modified if warranted. In cell B743, enter the one-way haul distance (ft) from the liner clay-soil source to the center of the area covered by the heap(s). Enter the total heap area (acres) to be capped in B744. The range assumes that the liner will be applied in 6-in lifts. Specify the number of lifts in B745. In cell B746, enter the thickness (ft) of the crushed rock drainage-protection layer. Enter the one-way haul distance (ft) from the crushed rock source to the heap area. In cells B784 and B864, enter the effective graded width (ft) per dozer pass (75% to 90% of the dozer blade overall width).

```
          A                B          C          D          E          F
681   ---PLASTIC POND LINER AND POND SEDIMENT DISPOSAL (1 of 3 screens)---
682   ************************************************************************
683     **Are you going to bury or                    (Note: M=1,000)
684
685     remove the liner?        remove     (bury or remove)
686   ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
687     **PREGNANT POND                  0 Msft      THICKNESS          80 mil
688     **BARREN POND                    0 Msft      THICKNESS          80 mil
689     **EMERGENCY OVERFLOW POND        0 Msft      THICKNESS          80 mil
690   ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
691     **Are you going to bury or
692     remove pond sediment?    remove     (bury or remove)
693     **SEDIMENT AMOUNT                0 st
694     **HAUL DISTANCE                  0 mi
695     **UNIT DISPOSAL FEE          $0.00 per st
696     SEDIMENT DENSITY                20 cft/st    assumed
697   ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
698     TOTAL DISPOSAL COST                    (Note: you cannot remove liner
699     ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~   and bury sediment)
700     LINER AND SEDIMENT             $0
```

Figure 19.—Plastic pond liner and pond sediment disposal screen.

```
          A                B          C          D          E          F
741   ---CAPPING HEAP (1 of 7 screens)---
742   ************************************************************************
743     **HAUL DISTANCE - CLAY           0 ft
744     **ACRES TO CAP                   0 ac
745     **CLAY LIFTS (6 IN EACH)         2
746     **DRAINAGE LAYER                 1 ft
747     **HAUL DISTANCE - ROCK           0 ft
748
749     CLAY THICKNESS                   1 ft
750     CLAY VOLUME                      0 cyd
751     CRUSHED ROCK VOLUME              0 cyd
752
753
754
755
756
757
758     TOTAL CAPPING  COST            $0
759
760
```

Figure 20.—Capping heap screen.

SEED AND FERTILIZER COST LIST (G61..L600)

This section includes 26 screens of seed and fertilizer cost information to be used with the SEED AND FERTILIZER SELECTION SCREENS (A481..F560). The list is divided into six segments: GRASSES (G61..L397), FORBS (G398..L496), ADDITIONAL SEED MIXES (G497..L516), SHRUBS (G517..L550), TREES (G551..L583), and FERTILIZER (G584..L600). Refer to figure 1, HEAPREC SCHEMATIC, for the relative location of the section and the section's contents. As shown in figure 21, seed information included are the species common name, $/lb of pure live seed, and the number of seeds per ft^2, if the application rate is 1 lb/acre. If a particular seed is not in the list, go to ADDITIONAL SEED MIXES (G497) and enter the common species name in column G and the cost in column I. If a fertilizer mixture is not included, go to the end of the entries in FERTILIZER (G584); enter a description in column G, and cost per unit in column I. The SEED AND FERTILIZER SELECTION SCREENS (A481..F560) describe how to use this list. Seed and fertilizer costs are in 1991 dollars.

```
                G                   H          I          J          K          L
61     ---SEED AND FERTILIZER COST LIST---
62     ********************************************************************************
63     I.  GRASSES
64     ================================================
65
66     SPECIES NAME                              PLS      SEEDS/SF
67     (common - commercial variety)           COST/LB    @1 LB/AC
68     ================================================
69     BLUEGRASS:
70     ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
71     Big bluegrass - Sherman                   $4.01       20.7
72     Bulbous bluegrass - VNS                   $1.29       10.6
73     Canada bluegrass -                        $1.72       57.4
74     Reubens Canby bluegrass                   $6.11       21.3
75     - Canbar Kentucky                         $3.44       49.4
76     bluegrass - A-34                          $3.44       49.4
77     Kentucky bluegrass - Adelphi Kentuc       $2.65       49.4
78     Kentucky bluegrass - Argyle               $1.07       49.4
79     Kentucky bluegrass - Banff                $1.95       49.4
80     Kentucky bluegrass - Baron                $2.46       49.4
                                                            CALC
```

Figure 21.—Seed and fertilizer cost list screen.

CYANIDE DETOXIFICATION SECTION

The CYANIDE DETOXIFICATION SECTION (M1..BU200) includes four ranges: WATER RINSE (M1..Y200), SULFITE-AIR (AC1..AO200), CHLORINATION (AS1..BE200), and HYDROGEN PEROXIDE (BI1..BU200), for determining costs for detoxifying cyanides at cyanide heap leach operations. Refer to figure 1, HEAPREC SCHEMATIC, for the location of this section. Each range is a stand-alone method for detoxifying cyanides and requires independent assessment. A brief discussion about considerations for heap leach detoxification cost estimation are included in BACKGROUND, following this section. For additional background data on each of the methods refer to CYANIDE DETOXIFICATION METHODS (appendix C).

For comparison, each of the detoxification methods can be evaluated; however, costs representing only one of the techniques can be included at a time on the BOND ESTIMATE COST SUMMARY (A21..F40). Remember to designate the detoxification technique chosen in cell B33 of the BOND ESTIMATE COST SUMMARY.

There are 10 screens for calculating costs related to each of the detoxification methods. They are BASIC DATA, OPERATING COST SUMMARY, CAPITAL COST SUMMARY, LABOR COSTS, SUPPLY COSTS, EQUIPMENT OPERATING COSTS (2 screens), and EQUIPMENT CAPITAL COSTS (3 screens). Extra lines are provided on the LABOR, SUPPLY, EQUIPMENT OPERATING, AND CAPITAL COST screens for additional items as necessary.

The screens for all four detoxification ranges are in the same relative position. Data input and calculation cells for each range are aligned vertically in the template; therefore, comparable data for any of the ranges may be accessed by moving the cursor laterally with **<Ctrl> RIGHT** and **<Crtl> LEFT**. The cell designations in the following discussion are for chlorination only, but are relative for the other ranges.

Due to the similarity in data required to evaluate each of the cyanide detoxification processes, the following discussion on background and data input is generally applicable to all four processes. Where needed, specific comments pertaining to one of the four techniques are also included.

BACKGROUND

All four detoxification methods involve application of rinse waters to the heap, collection of heap effluent in an existing pond, and subsequent degradation of cyanides, with or without the use of reagents, until neutralization criteria are met. Many inactive heaps contain large tonnages; neutralization of the contained cyanide in a reasonable time, 3 or less years, will be a major undertaking. One of the significant factors for determining heap detoxification cost is the total project time. To determine total project time, critical input data are area rinsed per cycle, number of pore volumes, and solution application rate. For the user to observe the effect that changing these critical items has on project length, it is recommended that HEAPREC be turned to automatic recalculation for these inputs ("/", Worksheet, Global, Recalculation, and Automatic).

One of the underlying assumptions for detoxification cost estimation is that the solution flowrates will not substantially exceed that of the original heap operation. In general, detoxification treatment rates are somewhat constrained by the original facilities design. Without alteration of pond and piping sizes, it is generally infeasible to consider significantly increasing solution application, recovery, and treatment rates. This assumption is implicit in the lack of expenditures for site modification. Usual heap rinse application rates are 0.003 to 0.005 gal/min/ft^2; these rates also coincide with typical application rates for the cyanide leach solutions. If higher rinse solution application rates are considered, higher capacity pumps and piping must be purchased or active rinsing must be limited to smaller areas. Heap instability can be created by high solution application rates. Consider monitoring the heap solution level if the rinse solution application rate exceeds the designed leach solution application rate.

Past practice has called for continuous circulation of rinse solutions through the heap. Recent findings, however, suggest that alternating rinse periods with periods during which the heap is allowed to drain (rinse-rest) may increase the effectiveness of the cyanide destruction treatment techniques. If rinse-rest techniques are incorporated as part of the detoxification procedure, adjustments should be considered in the operational plan used to calculate the detoxification costs.

BASIC DATA (AS1..AZ20): As shown in figure 22, this screen is divided into two columns; INPUT DATA, which contains the information describing the heap to be treated and OUTPUT data, which uses equations contained in each cell to calculate additional characteristics of the heap based on engineering design factors.

In cell AU5, enter the amount of material (st) contained in the heaps to be treated. Refer to the current or proposed plan of operations for the mine under evaluation. Average heap thickness (ft) is input in cell AU6. In cell AU7, the heap dry density (lb/ft^3), dry unit weight of the heap material, is input. Inputs generally range from 80 to 120 lb/ft^3. The lower values are typical of shaley

	AS	AT	AU	AV	AW	AX	AY	AZ
1	CHLORINATION - (1 of 10 screens)				COST		ERR	
2			BASIC DATA					
3								
4	INPUT				OUTPUT			
5	AMOUNT TO TREAT		0	st	HEAP VOLUME		0	cft
6	APPLICATION RATE		0.005	gpm/sft	PORE VOLUME		0	cft
7	HEAP THICKNESS		0	ft	RINSE VOLUME		0	gal
8	RINSE DAYS		0	d/yr	TOTAL HEAP AREA		ERR	sft
9	RINSE PANEL AREA		200000	sft	RINSE VOL/AREA		ERR	gal/sft
10	RINSE PANEL AREA		4.6	ac	RINSE PANEL CYCLE		ERR	d
11	HEAP DRY DENSITY		100	lb/cft	# RINSE PANELS		ERR	
12	PORE SPACE		38	% vol	TOTAL TREAT TIME		ERR	d
13	NO OF PORE VOL		0		PUMP RATE		ERR	gpm
14	CN IN SOLUTION:							
15	AVERAGE		100	ppm	CHLORINE RATE max		ERR	lb/min
16	MAXIMUM		400	ppm	LIME FEED RATE max		ERR	lb/min
17	RETENTION TIME		60	min	REACTION POND VOL		ERR	cft
18	ELECTRICITY		0.05	$/KWh	LIQ Cl STORAGE		ERR	cft
19	TOTAL HEAP AREA		ERR	ac	DRY LIME STORAGE		ERR	cft
20								

Figure 22.—Basic data screen.

materials, whereas denser rock materials, such as fresh basalts, are characterized by highest values. If necessary, heap density may be calculated using the following equation,

$$D = SG \times 62.4 \times (1\text{-}pS/100),$$

where D = heap density (lb/ft^3),

SG = specific gravity of the rock type (s.g.),

and pS = pore space in the heap (%).

Pore space (volume percent), the measure of the interstitial void space both within and between rock fragments within the heap, is input in cell AU12. There are several definitions of pore volume currently being used, including the pore space existing after allowing the heap to drain completely. The volume of liquid retained through capillary action, is a measure of the "specific retention" of the heap. To simplify the calculations contained in HEAPREC, specific retention values are ignored and values input should assume that the heap material is dry, that is, all free moisture is removed. In general, this value ranges from 25% to 40%, with shaley materials at the low end and fresh granitic material at the upper end.

The number of pore volumes—the amount of rinse solution which passes through a unit volume relative to the pore space present—is entered in cell AU13. These values can be determined by previous operational experience at the heap under investigation or similar facilities elsewhere, or through laboratory testing using characteristic heap material samples. Depending on ore characteristics, 2 to 10 pore volumes have shown to effectively reduce cyanide levels to permissible levels under laboratory conditions.

The number of operational days per year when rinsing and effluent treatment is ongoing is placed in cell AU8. If the operation is less than 1 year, input the total number of rinse days here. For warm climates, it is possible to rinse and treat an inactive heap year-round; however, in cooler climates freezing conditions may not only preclude solution application, but inhibit the chemical reactions necessary in the treatment process. In cold climates it may be necessary to reduce the number of operating days per year. Allowing for temporary shutdowns due to technical problems, 300 d/yr is feasible in warm climates; in cooler climates, 200 d/yr is more typical.

The rate of solution application (gal/min/ft^2) is placed in cell AU6. During leaching this value ranges from 0.003 to 0.005 gal/min/ft^2; however, rinsing rates may be as great as 0.01 gal/min/ft^2 or more.

Two measures of CN levels in the heap effluent (mg/L CN) are required for this evaluation. They are the average value contained in the effluent throughout a single rinse cycle (cell AU5) and the maximum cyanide value (cell AU6), which usually occurs at the commencement of treatment. If this data is unavailable, the average value may be estimated as 25% of the maximum cyanide value. In general, treatment facilities are designed using the maximum levels, whereas operational items such as reagents are determined using average cyanide values. Depending upon applicable regulations, these values will represent total cyanide, weak acid dissociable cyanide, or free cyanide. For total cyanide readings effluent values

range from as little as 10 mg/L to as great as 2,000 mg/L. Maximum content in heap leach effluent is more generally 100 to 500 mg/L total CN.

The retention time (min) required for effluent treatment using the detoxification method is input in cell AU7. As this value tends to decline during each rinse cycle, it is important to include the maximum time, that is the time required at the beginning of the rinse cycle, for planning purposes. Time requirements are site and process dependent. If laboratory information is unavailable for a specific ore, the following inputs are recommended:

Chlorination	- 120 min
Hydrogen peroxide	- 30 min
Sulfite-air	- 60 min.

Current electrical power rates($/kW·h) for the heap operation being evaluated should be entered in cell AU8. If unavailable at the site, western U.S. power rates range from 3 to 8 cents and average 5 cents/kW·h. If the power is to be generated on-site, 10 cents/kW·h is a reasonable approximation.

The rinse panel area (ft^2), entered in cell AU9, is the area being rinsed at any one time. In general, it will be a small fraction of the total heap area. The subsequent value, the number of acres, can not be entered but is calculated by the computer automatically. Generally, inputs range from less than 10,000 ft^2 to as great as 1 million ft^2 (see also Area rinsed equation in appendix E). NOTE: If the rinse panel area input here exceeds the total heap area calculated in the OUTPUT column, the latter half of the OUTPUT column will show an error message (ERR) instead of calculated values.

OPERATING AND CAPITAL COST SUMMARIES (AS21..AZ60): Both operating and capital cost summary tables are generated automatically for each detoxification method assessed, following completion of the design and cost estimation phases of the analysis. These tables are located in the two screens found just below the input data screen for each of the four treatment methods.

The operating summary (fig. 23) includes values for labor, supplies, and equipment operation and are specified as total cost and as dollars per short ton treated. Capital costs (fig. 24) are given as charges for equipment or material, installation, and freight. These costs have also been divided as those relating to treatment facilities and those related to solution application and recovery.

LABOR COSTS (AS61..AZ80): Labor requirements include supervisory personnel, treatment equipment operators and helpers, and truck drivers. If it is felt that additional categories are required, they may be added in the table on lines with **BLANK** in the category cell (fig. 25). Labor rates in dollars per hour are input in cells starting with AV..66. Hourly rates input should include both the base rate and all burden charges. Daily labor requirements for each category are also input directly commencing with cell AU66. These values are determined by estimating the number of shifts required daily and multiplying this figure by the number of hours per shift.

On the basis of the input data, costs are calculated on a daily and project basis for each labor type. Following summation, a factor is applied to account for nonoperational time as downtime and set-up and tear down. Total labor cost per short ton is also computed.

SUPPLY COSTS (AS81..AZ100): Supply requirements include treatment reagents for the three chemical treatment methods (chlorination, hydrogen peroxide, and sulfite-air), and rinse panel sprinkler and distribution system installation for all four treatment methods. As shown in figure 26, it is necessary to input the average reagent requirements, beginning with AT87, on a pound reagent per pound cyanide treated basis. These quantities may be estimated from similar operations or by actual or experimental data from the operation under consideration. Initial values contained on the screen are mid-range use rates based on literature. Reagent costs, on a per pound basis, must also be input starting at cell AV87. As this number is multiplied by the use amount discussed above, charges must reflect the form of the reagent used to compute the use rate. For example, if the use rate for copper is reported in the ionic form and yet this reagent is purchased in the sulfate form, adjustment to the cost number must be made to reflect the cost per pound cupric ion. NOTE: The supply cost screen for the sulfite-air detoxification process includes an input for royalty (cell AE99). The INCO process is the only method known at this time to have such a cost. The rate for this royalty is currently $0.35/lb of sulfite consumed during solution treatment.

EQUIPMENT OPERATING COSTS (AS101..BE140): Two screens are used to list the equipment selected to treat the heap with the process under consideration, and specify the hourly costs for each item and the number of hours each is operated daily. The first of these two screens is shown in figure 27. Specific items included are reaction tanks, pumps, compressors, trucks, and reagent storage facilities. The number of each of these items will have been specified by the type of process under consideration and their capacity is determined by the system flowrate.

The equipment operation cost screens are divided into a rating column which contains input or calculated rating values for the equipment listed, hourly maintenance charges (lube-fuel, parts, and repair labor) for the equipment selected, and summations of all charges for each item. To complete this table it is necessary to pick specific pieces of equipment, based upon the ratings given in the RATING column, and to consult published or unpublished

	AS	AT	AU	AV	AW	AX	AY	AZ
21	CHLORINATION - (2 of 10 screens)							
22			OPERATING COST SUMMARY					
23								
24			ITEM		($/ST)	TOTAL		
25								
26			LABOR		ERR	ERR		
27			SUPPLIES		ERR	ERR		
28			ROYALTY/SPEC EQ RENTL		$0.00	$0		
29			EQUIPMENT OP		ERR	ERR		
30								
31			TOTALS		ERR	ERR		
32								
33								
34								
35								
36								
37								
38								
39								
40								

Figure 23.—Operating cost summary screen.

	AS	AT	AU	AV	AW	AX	AY	AZ
41	CHLORINATION - (3 of 10 screens)							
42			CAPITAL COST SUMMARY					
43								
44			ITEM		TRTMENT	HEAP	TOTAL	
45								
46			EQUIPMENT/MATERIAL		$210,868	$32,892	$243,760	
47			INSTALLATION		$27,231	$9,819	$37,050	
48			FREIGHT		$869	$497	$1,366	
49								
50			TOTALS		$238,968	$43,208	$282,176	
51								
52								
53			SHORT TONS TREATED		0			
54			TOTAL LB CN TRTED		0			
55			DOLLARS/LB CN TREATED		ERR			
56								
57								
58								
59								
60								

Figure 24.—Capital cost summary screen.

	AS	AT	AU	AV	AW	AX	AY	AZ
61	CHLORINATION - (4 of 10 screens)							
62				LABOR COSTS				
63								
64	LABOR		HR/DAY	COST/HR	COST/DAY	PROJECT COST		
65								
66	SUPERVISOR		8	$40.00	$320	ERR		
67	OPERATORS		24	$30.00	$720	ERR		
68	DRIVERS		8	$25.00	$200	ERR		
69	HELPERS		16	$20.00	$320	ERR		
70	<BLANK>				$0	ERR		
71	<BLANK>				$0	ERR		
72	<BLANK>				$0	ERR		
73	<BLANK>				$0	ERR		
74	<BLANK>				$0	ERR		
75	<BLANK>				$0	ERR		
76								
77					$1,560	ERR TOTAL COST		
78								
79	DOWN TIME =		0.25			ERR COST/ST		
80	(AS DECIMAL OF RINSE TIME)							

Figure 25.—Labor cost input screen.

	AS	AT	AU	AV	AW	AX	AY	AZ
81	CHLORINATION - (5 of 10 screens)							
82				SUPPLIES				
83								
84	SUPPLIES	LB/LB CN	UNIT/ST	COST/UNIT	COST/ST	PROJECT COST		
85								
86	REAGENTS							
87	LIQ CHLO	6.83	ERR	$0.10	ERR	ERR		
88	LIME	3.1	ERR	$0.05	ERR	ERR		
89	<BLANK>	0	ERR	$0.00	ERR	ERR		
90	<BLANK>	0	ERR	$0.00	ERR	ERR		
91	<BLANK>	0	ERR	$0.00	ERR	ERR		
92	<BLANK>	0	ERR	$0.00	ERR	ERR		
93	PIPING				ERR	ERR		
94					----------			
95					ERR	ERR		
96								
97								
98								
99								
100								

Figure 26.—Supply cost input screen.

	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE
101	CHLORINATION - (6 of 10 screens)												
102				EQUIPMENT OPERATING COST									
103													
104	EQUIPMENT OPERATN			RATING	HR/DAY	LUBE/FUEL	PARTS	RPR LABOR	HPOWER	ELECT.	DEPRCTN	TOTAL	COST/DAY	SOURCE
105													
106	AGITATION MOTOR:												
107	LIME (gal)				24	$0.02	$0.10	$0.10	1	$0.04	$0.14	$0.40	$9.60	EST
108					24									
109	PUMPS SOLN:				24									
110	SOLN RTRN (gpm)				24	$0.07	$0.94	$1.08	60	$2.24	$1.57	$5.90	$141.60	CRG
111	LIME SOLN (gpm)				24				2	$0.07		$0.07	$1.68	EST
112	CHLORINE SOLN(gpm)				24	$0.05	$0.45	$0.55	5	$0.19	$0.80	$2.04	$48.96	EST,boost
113					24									
114	LIME STORAGE (cft)				24									
115	FEEDER(lb/hr)				24	$0.02	$0.20	$0.20	2	$0.07	$0.40	$0.89	$21.36	EST
116	<BLANK>				24	$0.00	$0.00	$0.00	0					
117	<BLANK>				24	$0.00	$0.00	$0.00	0					
118	<BLANK>				24	$0.00	$0.00	$0.00	0					
119	<BLANK>				24	$0.00	$0.00	$0.00	0					
120	(cont. below)													

Figure 27.—Equipment operating cost screen.

cost references for representative costs. Popular sources for deriving equipment and/or labor operating costs are:

(1) Dataquest Inc. Cost Reference Guide for Construction Equipment. The Dun & Bradstreet Corp., San Jose, CA, 1990, 23 sections.

(2) Mahoney, W. D. (ed.). Construction Cost Data, Western Edition. R. S. Means Co., Inc., 1991, 502 pp.

(3) Mahoney, W. D. (ed.). Heavy Construction Cost Data, Western Edition. R. S. Means Co., Inc., 1991, 404 pp.

(4) Richardson Engineering Services, Inc. The Richardson Rapid Construction Cost Estimating System. Richardson Engineering Services, Inc., Mesa, AZ, 1991, vol. 1-4.

(5) Western Mine Engineering. Mining Cost Service. Spokane, WA, 1990.

In a few instances, equipment size cannot be directly related to system capacity parameters; therefore, the evaluator should determine the rating for entry in these cases. An example of this is the load ratings of the service truck.

As an aside, if in subsequent evaluations, different sources for specific equipment operational data are used, they should replace those currently in the SOURCE column. The cited references, from which the equipment hourly charges are derived, also provide quotes for the attached motors driving each piece of equipment. It is important that these values be encoded in the HORSEPOWER column as they dictate power costs.

Two incidental items included at the base of the equipment operation table are instrumentation operation charges and sampling costs. They are specified as a decimal of the equipment operation cost, modify th decimal values if warranted.

CAPITAL COSTS (AS141..AZ200): This is a three screen range used to identify the capital cost of equipmen or other significant items which cannot be readily charge to the operating rate. The first two screens include item such as storage tanks, office space, and instrumentation The last range includes the information necessary to esti mate the cost of the initial piping follows.

As shown in figure 28, the costs per item are broke down into individual equipment cost or cost per foot installation cost, freight charges, and taxes. This rang totals these costs for inclusion into the detoxification cos summary. The equipment types required are identified Sizing for the equipment has been calculated in the pre vious operating cost range or the initial basic data cal culations. This range also facilitates the referencing o cost sources.

Specific input required is office space for the on-site staff, the total weight of each item and its price, instal lation charges for placing the item in service on-site, an freight charges necessary to transport it to the site. Al though unnecessary for the cost estimation, space is pro vided at the end of each line to include the source of th cost data for future reference.

The third screen—the piping installation screen— contains the cost for installing a solution distributio system. It requires specification of the length of mainlin piping from the treatment area to the heap, distributio lines on the heap, and the number of joints and spra heads to complete the system. Standard references for th cost of these items will also specify their unit weight fro which appropriate freight charges can be estimated.

	AS	AT	AU	AV	AW	AX	AY	AZ	BA
141	CHLORINATION - (8		of 10 screens)						
142			CAPITAL COSTS						
143									
144	ITEM		RATING	COST($)	INSTAL'N	FREIGHT	TOTAL	WT(LBS)	SOURCE
145									
146	AGITATION TANK:								
147	LIME(gal)			$544	$747	$61	$1,352	110	RICHARDSON
148	MIXER(hp)			$780	$560	$51	$1,391	69	RICHARDSON
149							$0		
150	PUMPS SOLN:						$0		
151	SOLN RTRN(gpm)			$12,950	$2,240	$287	$15,477	840	RICHARDSON
152	LIME SOLN(gpm)			$2,016	$747	$61	$2,824	115	RICHARDSON
153	CHLORINE SOLN(gpm)			$10,079	$3,733	$303	$14,115		RICHARDSON
154							$0		
155	LIME STORAGE(cft)			$14,500	$7,690		$22,190		RICHARDSON
156	FEEDER(lb/hr)			$4,675	$560	$106	$5,341	225	RICHARDSON
157							$0		
158							$0		
159							$0		
160	(cont. below)								

Figure 28.—Capital cost screen.

MACROS SECTION (BY1..CN317)

Macros have been developed to assist the user in clearing the entire template and printing the template in segments. A listing of the macros is presented in table 2. The macro for clearing the spreadsheet (press the <Alt> and C keys simultaneously) will erase all data entry cells and replace the cell contents with a zero (0). **Do not execute the clear macro unless the current version of input has been saved** ("/", File, Save, enter unique name at the prompt). There are 11 print macros, each of which prints a portion of the template. Before executing the print macros, make sure all data entry is complete and that all calculations have been executed (i.e., if CALC appears in the bottom right of the screen, press F9). The clear macro listing is located in cell CD3 and the print macro listing begins in cell CG1.

Table 2.—HEAPREC macros

FUNCTION	MACRO KEYSTROKES
Clear spreadsheet	<ALT> C
Print spreadsheet segments:	
Bond Estimate Cost Summary	<ALT> S
Indirect Reclamation Cost Summary	
Subsoil Earthwork Cost Summary	
Topsoil Earthwork Cost Summary	
Seeding Cost Summary	
Scraper - Subsoil Earthwork	<ALT> E
Wheel Loader - Subsoil Earthwork	
Loader-Truck - Subsoil Earthwork	
Dozer - Subsoil Earthwork	
Backhoe - Subsoil Earthwork	
Dozer - Recontour Heap	
Dozer - Grade Level Area, Subsoil	
Dozer - Grade Slopes, Subsoil	
Dozer - Ripping, Subsoil	
Dozer - Topsoil Application	<ALT> T
Scraper - Topsoil Application	
Wheel Loader - Topsoil Application	
Wheel Loader-Truck - Topsoil Application	
Dozer - Grade Level Area, Topsoil	
Dozer - Grade Slopes, Topsoil	
Motor Grader - Grading, Topsoil	
Seed and Fertilizer Mixes	<ALT> P
Mulch	
Broadcast Wet or Dry Application	
Dozer - Crimping	
Erosion Control Blankets	
Planting Trees and Shrubs	
Structure Demolition	<ALT> O
Liner-Sediment Disposal	
Capping Heap	
Equipment Selection	<ALT> D
Labor Selection	
Seed and Fertilizer Cost List	<ALT> G
Detoxification Ranges:	
Water Rinse	<ALT> W
Sulfite-Air	<ALT> X
Chlorination	<ALT> Y
HP_x	<ALT> Z

REFERENCES

1. Ahsan, M. Q., A. Griffith, and E. P. Jucevic. Detoxification of Spent Heaps with Hydrogen Peroxide. Ch. in Gold Forum on Technology and Practices—World Gold '89, ed. by R. B. Bhappau and R. J. Harden. (Proc. of the First Joint Int. Meeting between SME and AusIMM, Reno, NV, Nov. 5-8, 1989). Soc. Min. Eng. AIME, 1989, pp. 270-272.

2. Albrechtsen, B. R-4 Plant Species List for Reclamation of Disturbed Sites. U.S. Forest Service (Dep. Agriculture), Ogden, UT, 7 pp.

3. Caterpillar Tractor Company. Caterpillar Performance Handbook. Peoria, IL, 1988, 927 pp.

4. Culwell, L. D., W. S. Lyle, and L. A. Larsen. Reclamation at the Zortman-Landusky Mines Little Rocky Mountains. Pres. at Site Design, Construction and Reclamation of Cyanide Heap Leach Projects Short Course, Butte, MT, Mar. 19-22, 1990, 61 pp.; available from Minerals and Geology Staff, Region 1, U.S. Forest Service, Missoula, MT.

5. Degussa Corporation. H_2O_2 Product Information. Product Brochure No. 4, May 1988, 4 pp.

6. DeVries, F. W. Some New Developments in Using Hydrogen Peroxide to Detoxify Mill Effluents. Paper in Proceedings of Gold Mining Treatment Seminars, Vancouver, British Columbia, Canada, Feb. 15-16, 1989, and Mississauga, Ontario, Canada, Mar. 22-23, 1989. Environ. Can., 1989, pp. 259-263.

7. ____. Stability of Arsenic Precipitates from Kastone Peroxygen Product Cyanide Destruction. Paper in Proceedings of Gold Mining Treatment Seminars, Vancouver, British Columbia, Canada, Feb. 15-16, 1989, and Mississauga, Ontario, Canada, Mar. 22-23, 1989. Environ. Can., 1989, pp. 259-263.

8. DeVuyst, E. A. INCO's Cyanide Removal Technology Working Well. Min. Eng., v. 43, No. 2, 1991, pp. 205-207.

9. DeVuyst, E. A., B. R. Conrad, and W. Hudson. Commercial Operation of INCO's SO_2/Air Cyanide Removal Process. Paper in Cyanide and the Environment, ed. by D. J. A. van Zyl (Proc. Conf. Univ. AZ, Tucson, AZ, Dec. 11-14, 1984). CO State Univ., Ft. Collins, CO, 1985, pp. 469-487.

10. E. I. du Pont de Nemours & Co. Kastone B Peroxygen Compound for Treatment of Mining Wastewater Containing Cyanide. DuPont Datasheet, Mar. 1984, 4 pp.

11. Englehardt, P. Long-Term Degradation of Cyanide in an Inactive Heap. Paper in Cyanide and the Environment, ed. by D. J. A. van Zyl. (Proc. Conf. Univ. AZ, Tucson, AZ, Dec. 11-14, 1984). CO State Univ., Ft. Collins, CO, 1985, pp. 539-547.

12. Ferguson, R. B., and H. E. Walker. Cyanide Destruction Processes. Can. Pat. 1,183,617, Mar. 5, 1985.

13. Griffiths, A. Advances in Effluent Treatment. Supplement to Min. J. (London), v. 315, No. 8085, Aug. 24, 1990, pp. 14-15.

14. ____. Treatment of Gold Mill Effluent with Hydrogen Peroxide: Operating Experience and Costs. Paper in Proceedings of the 21st Canadian Mineral Processors Conference, Ottawa, Ontario, Canada, Jan. 17-19, 1989. CANMET, 1989, pp. 145-155.

15. Haight, S. Cyanide Heap Neutralization at the Kendall Mine. Pres. at Site Design, Construction and Reclamation of Cyanide Heap Leach Projects Workshop, Butte, MT, Mar. 19-22, 1990, 10 pp.; available from U.S. Forest Service, Minerals and Geology Staff, Missoula, MT.

16. Hinkle, C. R., R. E. Ambrose, and C. R. Wenzel. A Handbook for Meeting Fish and Wildlife Information Needs to Surface Mine Coal-OSM Region V. U.S. Fish and Wildlife Service (Dep. Interior), Feb. 1981, 141 pp.

17. Hossner, L. R. (ed.). Reclamation of Surface-Mined Lands, Vol. I and II. CRC Press, Inc., 1988, pp. 219 and 250.

18. Huiatt, J. L. Problems and Research Needs. Paper in Cyanide and the Environment, ed. by D. J. A. van Zyl. (Proc. Conf. Univ. AZ, Tucson, AZ, Dec. 11-14, 1984.) CO State Univ., Ft. Collins, CO, 1985, pp. 519-530.

19. Knorre, H., and A. Griffiths. Cyanide Detoxification with Hydrogen Peroxide Using the Degussa Peroxide. Paper in Cyanide and the Environment, ed. by D. J. A. van Zyl. (Proc. Conf. Univ. AZ, Tucson, AZ, Dec. 11-14, 1984, pp. 519-530.

20. Lewis A. New Inco Tech Process Attacks Toxic Cyanides. Eng. and Min. J., July 1984, pp. 52-54.

21. Mahoney, W. D. (ed.). Building Construction Cost Data, Western Edition. R. S. Means Co., Inc., 1990, 502 pp.

22. McGill, S. L., and P. G. Comba. A Review of Existing Cyanide Destruction Practices. Pres. at Wildlife/Mining Workshop, Nevada Min. Assoc., Reno, NV, Mar. 29, 1990, 22 pp.; available from S. L. McGill, Reno Research Center, BuMines, Reno, NV.

23. Mudder, T. I. (ed.). The Chemistry, Analysis, Toxiciity, and Treatment of Cyanidation Wastewaters. Pres. at Soc. Min. Eng. AIME Short Course, Las Vegas, NV, Feb. 26, 1989, 350 pp.; available from SME Meetings Dept., Littleton, CO.

24. Narten, P. F., S. F. Litner, J. W. Allingham, L. Foster, D. M. Larsen, and H. C. McWreath, III. Reclamation of Mined Lands in the Western Coal Region. U.S. Geol. Surv. Circ. 872, 1979, 56 pp.

25. Olson, F. A., J. L. Huiatt, J. E. Kerrigan, and G. L. Potter (eds.). Proceedings of a Workshop: Cyanide from Mineral Processing, Utah Mining and Minerals Resources Research Institute, Feb. 2-3, 1982, Salt Lake City, UT, 1983, 123 pp.

26. Piret, N. L., and H. J. Schippers. Cyanide Destruction Versus Cyanide Regeneration - Evaluation of the Processes for Optimum Mill Effluent Treatment. Pres. at Mining and Metallurgy Symposium: Extraction Metallurgy '89, London, England, July 10-13, 1989, (pages unknown); available from S. L. McGill, Reno Research Center, BuMines, Reno, NV.

27. Richardson, B. Z. Reclamation in the Intermountain Rocky Mountain Region. Paper in Design of Non-Impounding Mine Waste Dumps, ed. by M. K. McCarter. Soc. Min. Eng. AIME, 1985, pp. 177-192.

28. Ritcey, G. M. Alkaline Chlorination. Sec. in Tailings Management, Problems and Solutions in the Mining Industry. Elsevier Sci. Publ., 1989, pp. 617-627.

29. Ritcey, G. M., and V. M. McNamara. Treatment of Gold Mill Effluents for Removal and Recovery or Destruction of Cyanide - A Summary of a Joint Project with Six Canadian Gold Mills. Paper in Proceedings of Tenth Annual Conference of Canadian Mineral Processors Meeting, Jan. 24-26, 1988, Ottawa, Ontario, Canada. CANMET, 1988, pp. 152-197.

30. Rolfes, S. R., Jr. Methods of Neutralizing Cyanide in Mining Wastes and Waste Waters. M.S. Thesis, MT State Univ., Bozeman, MT, 1989, 63 pp.

31. Scales, M. An Overview of Gold Mill Effluent Treatment. Paper in Proceedings of Gold Mining Effluent Treatment Seminar, Vancouver, British Columbia, Canada, Feb. 15-16, 1989 and Mississauga, Ontario, Canada, Mar. 22-23, 1989. Environ. Can., 1989, pp. 1-22.

32. Scott, J.S. An Overview of Cyanide Treatment Methods for Gold Mill Effluents. Paper in Cyanide and the Environment, ed. by D. J. A. van Zyl (Proc. Conf. Univ. AZ, Tucson, AZ, Dec. 11-14, 1984). CO State Univ., Ft. Collins, CO, 1985, pp. 307-330.

33. Ingles, J. C., and J. S. Scott. State-of-the-art Processes for the Treatment of Solid Mill Effluents. 1987, pages unknown; available from Can. Environ. Protection Ser., Ottawa, Ontario, Canada.

34. Smith, A. Cyanide Degradation and Detoxification in a Heap Leach. Ch. in Introduction to Evaluation, Design and Operation of Precious Metal Heap Leaching Projects, ed. by D. J. A. van Zyl, I. B. G. Hutchinson, and J. E. Kiel. Soc. Min. Eng. AIME, 1988, pp. 293-305.

35. Smith, A., and A. Brown. The Potential for Cyanide Migration from the Annie Creek Processing Facility. Steffen Robertson and Kristen Rep. No. 1086/2 to Wharf Resour. (USA), Inc. 1986, pages unknown; available from Wharf Resources Inc., Deadwood, SD.

36. Smith, A. and D. W. Struhsacker. Cyanide Geochemistry and Detoxification Regulations. Ch. in Introduction to Evaluation, Design, and Operation of Precious Metal Heap Leaching Projects, ed. by D. J. A. van Zyl, I. B. G. Hutchinson, and J. E. Kiel. Soc. Min. Eng. AIME, 1988, pp. 275-305.

37. Struhsacker, D. W., and A. Smith. Considerations in the Reclamation of Cyanide Heap Leach Dumps. Pres. at Intermountain Mining and Processing Symposium, Elko, NV, Nov. 3-5, 1988. 1988, 18 pp.; available from D. W. Struhsacker, Dames and Moore, Reno, NV.

38. Todd, L. Cyanide Degradation Study: Gold Fields Operating Co. - Mesquite. 1986, 18 pp.; available from California Regional Water Quality Control Board, Palm Desert, CA.

39. Tourbier, J. T., and R. Westmacott. A Handbook for Small Surface Coal Mine Operators (U.S. Office of Surface Mining (Dep. Interior) grant No. 14-34-0001-8900). Univ. DE, Newark, DE, 1980, 130 pp.

40. U.S. Forest Service (Dep. Agriculture). Cost Estimating Guide for Road Construction. Region 4, Div. Eng., June 1990, 53 pp., available from the U.S. Forest Service, Intermountain Region, Ogden, UT.

41. ____. R-4 Reclamation Field Guide. Region 4, Miner. Management, Ogden, UT, 1990, 81 pp.

42. U.S. Office of Surface Mining (Dep. Interior). Handbook for Calculation of Reclamation Bond Amounts. 1987, 19 pp.

43. U.S. Environmental Protection Agency. Treatability Manual, Vol. III. EPA-600/8-80-042. July 1980, 241 pp.

44. Vogel, W. G. A Manual for Training Reclamation Inspectors in the Fundamentals of Soils and Revegetation. Soil and Water Conserv. Soc., Sept. 1987, 178 pp.

45. Williamson, N. A., M. S. Johnson, and A. D. Bradshaw. Mine Wastes Reclamation. Min. J. Books Ltd., 1982, 103 pp.

BIBLIOGRAPHY

Barratt, D. J., and R. O. McElroy. Heap Leaching for Precious Metals. Eng. and Min. J., June 1990, pp. 40-46.

Belsky, E. M. Reclamation Bonds - Meeting the Requirements. Pres. at 95th Northwest Min. Assoc. Conv., Spokane, WA, Dec. 6-8, 1989, 5 pp.; available from Northwest Min. Assoc., Spokane, WA.

Brickell, R. H. Chemistry of Cyanide Solutions. Paper in Proceedings of Cyanide and the Gold Mining Industry Seminar, Ottawa, Ontario, Canada, Jan. 22-23, 1981. Environ. Can., 1981, pages unknown.

Buck, B. W., and S. A. Botts. Mine Reclamation Planning in the Great Basin. Pres. at Western Regional Symposium on Mineral Processing Wastes, Berkeley, CA, May 30-June 1, 1990, 11 pp.; available from B. W. Buck, JBR Consultants Group, Salt Lake City, UT.

Callahan, M. A., M. W. Slimak, N. W. Gabel, I. P. May, C. F.Fowler, J. R. Freed, P. Jennings, R. L. Durfee, F. C. Whitmore, B. Maestri, W. R. Mabey, B. R. Holt, and C. Gould. Water-Related Environmental Fate of 129 Priority Pollutants, Vol. I (U.S. EPA contracts 68-01-3852 and 68-01-3867). EPA 440/4-79-029a, 1979, 473 pp.

Chatwin, T. D. Cyanide Attenuation/Degradation in Soil - Final Report. 1989, 60 pp.; available from T. D. Chatwin, Resource Recovery and Conservation Consultants, Salt Lake City, UT.

Comba, P. G. and S. L. McGill. Rinsing of Spent Precious Metal Ores for Heap Leach Decommissioning. 1990, 13 pp.; available from P. G. Comba, BuMines-Reno Research Center, Reno, NV.

Dataquest Inc. Cost Reference Guide for Construction Equipment. The Dun & Bradstreet Corp., San Jose, CA, 1990, 23 sections.

Degussa. Detoxifying Mine Effluents Containing Cyanides. Product Brochure No. 2, Jan. 1988, 9 pp.

Devries, F. W. U.S. Leach Heap Detoxification. Paper in Proceedings of Gold Mining Effluent Treatment Seminars, Vancouver, British Columbia, Canada, and Mississauga, Ontario, Canada, Mar. 22-23, 1989, Environ. Can., 1989, pp. 252-257.

DeVuyst, E. A., B. R. Conrad, G. Robbins, and R. Vergunst. INCO SO_2/Air Cyanide Removal Process Update. Ch. in Gold Forum on Technology and Practices - World Gold '89, ed. by R. B. Bhappan and R. J. Warden (Proc. of the First Joint Int. Meeting between SME and AusIMM, Reno, NV, Nov 5-8, 1989). Soc. Min. Eng. AIME, 1989, pp. 353-356.

Echo Bay Minerals Company. Permanent Closure Plan Borealis Cyanide Leach Pads. 1990, 11 pp.

Engineering-Science-Design-Research-Planning. Heap Leach Technology and Potential Effects in the Black Hills (U.S. EPA contract 68-03-6289). EPA 908/3-86-002, 1986, 367 pp.

Griffiths, A. Advances in the Treatment of Gold Mill Effluents with Hydrogen Peroxide. Soc. Min. Eng. AIME 1988 Annu. Meeting, Phoenix, AZ, 1988, 5 pp.

Griffiths, A., H. Knorre, S. Gos, and R. Higgins. The Detoxification of Gold Mill Tailings with Hydrogen Peroxide. J. South African Inst. of Min. and Metall., v. 87, No. 9, Sept. 1987, pp. 279-283.

Hittman Ebasco Associates, Inc. Destruction of Cyanide in Wastewaters: Review and Evaluation (U.S. EPA contracts 68-03-3037 and 68-03-3197). EPA 600/2-88-031, 1988, 61 pp.

Industrial Environmental Research Laboratory. Leachability and Revegetation of Solid Waste from Mining (U.S. EPA contract 68-03-2846-04). EPA 600/2-82-093, 1982, 137 pp.

Mackey, J. H. Reclamation Bonding, One Surety's Perspective. Soc. Min. Eng. AIME preprint 89-100, 1989, 2 pp.

Marcus, J. Mining Environment, Financial Assurances for Mine Closure; A Discussion of the Issues. Eng. and Min. J., v. 191, No. 8, 1990, pp. 16E-16K.

McDonald, G. W. Demonstration Heap Leaching. CIM Bull., v. 82, No. 926, June 1989, pp. 40-45.

Mooiman, M. B., J. D. Miller, J. B. Hiskey, and A. R. Hendriks. Process Alternatives for Gold Recovery from Cyanide Heap Leach Solutions. Soc. Min. Eng. AIME preprint 83-424, 1983, 35 pp.

Ok Tedi Mining Ltd. Ok Tedi Monitoring. Supplement to Min. J. (London), v. 315, No. 8085, Aug. 24, 1990, p. 23.

Olson, F. A., J. L. Huiatt, J. E. Kerrigan. Proceedings of a Workshop: Cyanide from Mineral Processing. UT Min. and Miner. Res. Inst., Salt Lake City, UT, 1983, 121 pp.

Palmer, S. A. K., M. A. Breton, T. J. Nunno, and N. F. Surprenant. Alkaline Chlorination. Ch. in Metal/Cyanide Containing Wastes, Treatment Technologies. Noyes Data Corp., 1988, pp. 602-624.

PEI Associates, Inc. Gold/Silver Heap Leaching and Management Practices that Minimize the Potential for Cyanide Releases (U.S. EPA contract 68-02-3995). EPA 600/2-88-002, 1988, 103 pp.

Resource Technology Centre. Symposium - Heap Leaching of Gold in a Canadian Environment, Timmins, Ontario, Canada, May 25-26, 1988. Ontario Centre for Resour. Machinery Technol., Sudbury, Ontario, Canada, 1988, 206 pp.

Richens, R. T. Environmental Permitting Requirements for Mining Projects, Case History Costs, and Methods for Affecting Costs and Scheduling. Pres. to Univ. ID, Dep. of Metall. and Min. Eng., Moscow, ID, Dec. 8, 1988, 4 pp.; available from D. K. Denton, BuMines, Spokane, WA.

Rouse, J. V. Cyanide and the Environment. Supplement to Min. J. (London), v. 315, No. 8085, Aug. 24, 1990, pp. 18-19.

Scales, M. CMP Becoming Premier Technical Conference. Can Min. J., v. 110, No. 4, 1989, pp. 37-45.

___. Detour Lake Gold Mine to Grow. Can. Min. J., v. 111, No. 6, 1990, pp. 23-25.

Sendlein, L. V. A., H. Yazicigil, and C. L. Carlson (eds.). Surface Mining Environmental Monitoring and Reclamation Handbook. Elsevier Sci. Publ., New York-Amsterdam-Oxford, 1983, 750 pp.

Stebbins, S. A. Cost Estimating Handbook for Small Placer Mines. BuMines IC 9170, 1987, 94 pp.

van Zyl, D. J. A., I. B. G. Hutchinson, and J. E. Kiel. Introduction to Evaluation, Design, and Operation of Precious Metal Heap Leaching Projects. Soc. Min. Eng. AIME, 1988, 322 pp.

Walker, A. The Various Elements of Reclamation Bonding: Past and Present. Soc. Min. Eng. AIME preprint 89-91, 1989, 4 pp.

Western Mine Engineering. Mining Cost Service. Spokane, WA, 1990.

APPENDIX A.—BONDING

BACKGROUND

In the not-too-distant past, it was acceptable practice for mine operators to let nature reclaim minesites with little or no assistance from mankind. Changes in public attitude concerning acceptable land-use practices have resulted in Federal and State legislation that prohibit mine operators from abandoning minesites without due reclamation. Reclamation performance bonds have become the preferred method used by regulators to ensure that lands disturbed by mining are reclaimed to acceptable standards. In addition to conforming to generic reclamation standards, such as removing structures and recontouring and revegetating lands, cyanide heap leach operations must also meet cyanide detoxification requirements for all process solutions and solid materials.

A brief discussion on the bases for reclamation performance bonds and cyanide detoxification bonds are presented below.

Reclamation Performance Bonds

Stewardship of public lands is the primary role of Federal and State land managers, and reclamation is an integral part of that stewardship. Reclamation is generally required at all levels of mining activity on private and public lands. Any mining-related surface disturbances on Federal and State-owned lands requires the developer to submit for approval a plan of operations that specifies what the activity will entail. Further, the plan must identify how any adverse effects of the activity will be mitigated. In some instances, minor mining-related surface disturbance is allowed on private lands before county- and State-level regulations require compliance to operating and reclamation standards.

Mitigation of adverse environmental impacts posed by mining is a primary responsibility of public land managers. To ensure that mining-related disturbances will be adequately reclaimed, regulators can use a variety of mechanisms that include a combination of civil and criminal penalties, the establishment of mined-land reclamation funds that are monitored and funded by the industry and/or government, and reclamation performance bonds. Performance bonding has become the preferred mechanism because it provides monies directly to the regulator to complete reclamation in the event of nonperformance or forfeiture by the mine operator.

Typically, the reclamation performance bonding procedure is incorporated into the mine permitting process as prescribed by State and/or Federal regulations. Bonding regulations usually stipulate that the amount of financial assurance, often referred to as the "penal sum" or "surety penalty," guaranteed by the bond will be sufficient to remediate site conditions. The amount of the bond is generally calculated in one of two ways.

(1) The bond amount may be based on the full cost of a third party performing reclamation and post reclamation activities.

(2) The bond amount may be calculated on a dollar-per-acre basis, not to exceed a specified maximum value, then multiplied by the number of disturbed acres.

Cyanide Detoxification Bonds

Due to the surge in gold mining activity and perceived hazards of using cyanide for gold recovery, an additional layer of bonding regulations have evolved. These regulations and associated bonds, often referred to as chemical processing bonds, were specifically developed for mining operations that use chemical or biological lixiviants for processing ore. Chemical processing bonds provide regulators with added security that funds will be immediately available for response to an accidental release of toxic material or the abandonment of a site containing toxic materials.

With all of the preventative steps and requirements needed to gain operating permits, this type of bonding may be redundant. Most, if not all, mining companies maintain a liability insurance policy. If presumed chemical processing hazards do exist, it is more prudent from a cost basis to consider them in a liability insurance policy.

In regard to cyanide heap leach operations, chemical processing bonds usually have maximum and minimum bond levels and are designed primarily to cover the cost of responding to and the remediation of accidental releases of cyanide. For example, South Dakota requires a minimum bond of $25,000 and maximum bond of $500,000 for mineral processing operations that handle potentially hazardous substances, specifically cyanide, to recover metals. The release of a chemical processing bond is usually tied to neutralizing spent heaps and processing solutions to levels specified in cyanide detoxification standards and removal of all potentially hazardous chemicals from the property. As with the reclamation bonds, chemical processing bonds are generally calculated using one of two methods.

(1) The chemical processing bond amount may be based on a set fee per quantity of material processed over

a given period of time, such as tons of ore placed on a leach pad over a 1-year period.

(2) Chemical processing bond amounts may also be based on the estimated cost of detoxifying materials on-site, including solutions and material on leach pads.

PERFORMANCE BONDING

A performance bond is a financial assurance which guarantees that one party (mine operator) will perform to the terms and conditions of a written contract with another party (regulator). Performance bonding has become the preferred mechanism used by regulators to ensure that mine operators comply with reclamation requirements. Reclamation requirements for cyanide heap leach operations may include cyanide solution and solids detoxification; closure and rehabilitation of roads, mine waste dumps, leach pads, and open-pits; and removal of buildings, structures, and equipment. Performance bonding of mining operations includes three separate categories: (1) a written contract (bond form), (2) a method or type of bonding (full-term, or segmented), and (3) a bonding mechanism or instrument (corporate surety, negotiable security, cash, irrevocable letter of credit, etc.). Formulation of a performance bond designed to adequately protect the environment, while not placing undue burden on the regulator or operator, requires careful consideration of each of these categories. A brief discussion of important factors to consider from each of these categories follows.

Bond Contracts

The bond form is a legal contract which outlines the conditions of the agreement between the obligee (State and/or Federal regulatory body) and the principal (mine operator). Currently, each group of regulators has its own bond form which leads to inconsistencies and misunderstandings between the operator, regulator, and bonding institution (surety).

Bond forms should be concise, legally defensible documents that precisely (1) identify the parties involved, (2) refer to what is to be accomplished and when (reclamation plan and timetable), and (3) describe the bond release criteria. A detailed mine reclamation plan should be the primary document supporting the bond form. Every element of the reclamation plan and bond form should be understood and agreed to by all parties. Vague and ambiguous terms and conditions should not be used. For example, calculating a reasonably accurate bond amount is difficult if only obscure terms are used to define what reclamation activities will take place. Likewise, referring to reclamation in indefinite terms leads to various interpretations of what truly constitutes successful and complete reclamation. To avoid confusion, the obligee and principal should understand exactly what type of reclamation is to be accomplished and when the reclamation will be completed.

The bond release criteria should include specifications and definitions of what constitutes complete reclamation including detoxification and revegetation succession, as well as a timeframe for monitoring succession. All conditions on the bond form should be agreed to by all parties. If a third party (surety or lending institution) is required to fulfill a bond agreement, the third party should also be aware of and agree to the conditions stipulated on the bond form.

Historically, detailed reclamation planning has not been a requirement for obtaining an operating permit from regulatory agencies. However, this trend has reversed such that a detailed reclamation plan is a vital component of a complete plan of operations as required by most Federal and State regulators. It is important to note that there are practical limits to the amount of detail that can be included in a preproduction reclamation plan. However, the more detail that an operator can include will go a long way in answering questions and concerns of regulators and the public. A reclamation plan should be based on the post-mining use of the land (multiple-use, agricultural, industrial, recreational, etc.) and an accurate assessment of the site-specific characteristics that will influence the type and success of reclamation activities. Site-specific characteristics that need to be evaluated include surface and ground water hydrology, engineering geology, agrogeology, climate, vegetation, and wildlife. Reclamation plans should include considerations of the following:

(1) Reclamation deliverables including types of vegetation, areas to be revegetated, final slope requirements, structure and road removal, cyanide solution and solids detoxification methods, etc.

(2) Timeframe for completing reclamation activities, including which activities will be accomplished concurrent with mine development and production and which will be post-production activities.

To insure an appropriate bond amount is being held requires regulators to periodically review minesite activities and adherence to the site reclamation plan. The bond contract should be limited to the terms and conditions stipulated at the time the contract was written. However, provisions should be made for periodically updating reclamation costs so that the bond amount reflects reclamation requirements in current dollars. Review of the bond calculation method should also be periodically conducted to ensure that current and appropriate reclamation technologies are accounted for which may lessen the bond amount. Substantial revision of a mine operating plan

should also trigger a revision of the reclamation bond amount being held.

Bond Types

There are esssentially two bonding methods or bond types available for mineral operations—full-term bonds and segmented bonds. Each bond type has different economic advantages and/or disadvantages for the mine operator.

The most common bond type, or variations thereof, currently utilized is a full-term bond. The full-term bond holds the operator liable for the entire amount of the bond until all reclamation is completed, approved, and released. The obvious drawback to this type of bonding is that the operator is liable for the complete amount of the bond for the duration of the operation and reclamation. The entire capital or bonding credit is therefore unavailable to the operator for use for other purposes. Because these monies or bonding credits are not released until all reclamation activities are successfully completed and then approved by regulators, full-term bonding has the most potential for posing economic hardship on large- to small-scale operations.

There are two common types of segmented bonds, phased and incremental. Segmented bonds divide the bond into portions that when totaled equal the mandated bond amount. Segmented bonding holds the operator liable only for the amount of reclamation not yet completed and approved. Therefore, as reclamation is completed and approved, capital and/or bonding credits are released so that the operator can use them for other purposes.

Phased bonding separates reclamation into distinct tasks and, as each task is completed and approved by the regulator, the amount of bond covering that task is released to the operator. Common tasks may include recontouring waste dumps, structure removal, topsoil application, revegetation, monitoring successsion of revegetation, monitoring groundwater, etc.

Incremental bonding is based on a discrete amount of disturbed area. As more area is about to be disturbed, an additional increment of bond is calculated and held. Therefore, as the amount of disturbed area increases so does the total amount of the bond being held. Conversely, if a disturbed increment is concurrently reclaimed, the bond amount covering that increment is released. When compared to full-term bonding, incremental bonding has the opportunity to provide the regulator with more precision in determining a property's bond liability. And as experience is gained with reclamation activities on the property, regulators can more accurately assess environmental and public concerns as well as adjust costs for the effects of inflation or deflation.

There are common variations to all of the above bond types. In some situations, the operator may only be required to post a portion of the total calculated bond, often referred to as partial or limited bonding. Factors that determine whether regulators allow partial or limited bonding include (1) history of the operator's compliance, (2) size and type of operation and the potential for creating significant damage to other resource values, and (3) proximity to identified sensitive resources (wilderness areas, wild and scenic rivers, etc.). Historically, operators have been able to post limited bonds for heap leach operations; however, this is not the current bonding practice. Some States have regulatory statutes that restrict the total amount of a reclamation bond or a maximum per acre bond limit.

For mining companies and operators with multiple facilities in a State, it may be possible to consolidate all of the bonding obligations under a single "State-wide" bond. An increase in administrative efficiency for both the operator and regulator is the primary advantage of a State-wide bond. Currently, Nevada State law and the proposed BLM bonding policy have provisions to allow State-wide bonding.

Bonding Mechanisms

Bonding mechanisms include corporate sureties, cash deposits, irrevocable letter of credit, negotiable securities, cash collateral including certificates of deposit or assigned savings accounts, and bond pools. The following briefly discusses some of the benefits and drawbacks for the mine operator as well as the regulator of each bonding mechanism.

(1) A corporate surety does not obligate large sums of the mine operator's capital and is relatively easy to administer; however, small- to medium-scale mines have difficulty convincing surety underwriters that they are solvent and capable of meeting long-term financial burdens.

(2) Cash deposits in the form of currency, certified check, cashier's check, etc., do not require the involvement of third parties in the bonding process and the cash is readily accessible. The disadvantages of cash deposits are that the capital is unavailable to the operator and the funds do not earn interest.

(3) An irrevocable letter of credit is available through most financial institutions, can be converted to cash if required, and in most cases does not obligate the mine operator's capital. The disadvantages of an irrevocable letter of credit are that some mine operators will not meet the appropriate qualifications and the validity of the letter is usually limited to 1 year.

(4) Negotiable securities, such as U.S. Treasury bonds, bills, and notes, have the advantage of easily being convertible to cash and allow the mine operator to collect interest semiannually on the capital that has been set aside to cover the bond; the primary drawback is that the capital is unavailable to the mine operator. If considering this mechanism, note that the redeemable value of the security at any given time may not equal the face value of the security.

(5) Cash collateral mechanisms, such as certificates of deposits with interest paid monthly, have the benefits of being readily available if needed by the regulator; the primary detriment is that the capital is unavailable for the mine operator's use. If considering this mechanism, note that there is a penalty for early withdrawal and that there is a limit to the amount guaranteed by the Federal Deposit Insurance Corp.

(6) Reclamation performance bond pools have been established by States and mining organizations to assist operators in meeting bond requirements. Typically, bond pools are formed for small operators who do not have the available resources to secure another method of bonding. The bond pool usually requires the operator to pay an annual fee based on the operator's reclamation liability and ability to pay. The bond pool then covers the bond liability of the operator but often only to a set limit. Bond pools are typically self-regulated by the participants and provide competent small operators with a means to meet reclamation performance bond requirements.

SUGGESTED READING

(Performance Bonding)

Belsky, E. M. Reclamation Bonds - Meeting the Requirements. Pres. at 95th Northwest Min. Assoc. Convention, Spokane, WA, Dec. 6-8, 1989; 4 pp.; available upon request from Northwest Min. Assoc., Spokane, WA.

Marcus, J. Mining Environment, Financial Assurances for Mine Closure; A Discussion of the Issues. Eng. and Min. J., v. 191, No. 8, 1990, pp. 16E-16K.

APPENDIX B.—CYANIDE DETOXIFICATION REGULATIONS

CYANIDE TOXICITY AND CHEMISTRY

A discussion on cyanide detoxification regulations is not complete without providing some background on cyanide toxicity and chemistry. A basic understanding of cyanide toxicity and how cyanide chemically interacts in the environment are prerequisites to understanding if cyanide detoxification requirements are appropriate for heap leach operations. The following discussion is not intended to be a treatise on cyanide toxicity and chemistry, but it will provide some basic data on these topics.

The chemistry of cyanide is complex. Cyanide can exist as a gas adsorbed on solid matrices, or dissolved in aqueous solutions. Cyanide and cyanide-related compounds can also exist in cyanide leach solutions as molecular hydrogen cyanide, free cyanide ions, thiocyanate, various metal complexes, and cyanate. Each of these compounds is subject to a variety of mechanisms that control its fate and transport in the environment.

To understand information about cyanide toxicity and chemistry requires a rudimentary understanding of the terminology used to refer to cyanide and cyanide compounds. Table B-1 presents a listing of cyanide definitions often used in discussions about toxicity and regulations. The definitions are based on analytical techniques used to determine cyanide concentrations in solutions.

Table B-1.—Cyanide definitions

Term-Analytical technique	Compounds identified
Free cyanide (CN_F)	HCN^-, CN^-.
Weak-acid-dissociable cyanide (CN_{WAD}).	CN_F compounds plus:
(a) relatively soluble compounds.	Na^+, K^+, Ca^{+2}, Mg^{+2}
(b) relatively insoluble compounds.	Zn, Cd, Ag, Cu, Ni.
Total cyanide (CN_T)	CN_F and CN_{WAD} compounds plus:
(a) very insoluble and stable compounds.	Fe, Co, Au, Pt, Hg.

Source: (25)[1]

[1]Numbers in parentheses refer to items in the list of references preceding appendix A.

Free cyanides are the most toxic and unstable forms of cyanide and include simple cyanide compounds. Free cyanides are referred to as "ephemeral toxins" because they are transient and tend to form more stable and less toxic compounds rapidly in ambient conditions. Free cyanides are rapidly detoxified using natural and chemical degradation processes. The analytical technique for determining free cyanide is subject to interference from thiocyanates, sulfates, oxidizing agents, nitrates, urea, and other organic compounds.

As shown in table B-1, WAD (weak-acid-dissociable) cyanides include all of the free cyanides as well as most simple cyanide complexes that are less toxic and more stable than free cyanides. WAD cyanides as a group can be detoxified using natural and chemical detoxification methods, however, they do not react as readily as the free cyanide components of the WAD cyanides. Of all cyanide analyses, WAD cyanide analyses are least effected by interferences and more reliable.

Total cyanides include cyanides detected with the WAD cyanide and free cyanide analyses, as well as cyanide compounds that are less toxic and more stable than WAD cyanides. By and large, the additional compounds detected with the total cyanide analysis can be considered stable under ambient conditions and react to a few aggressive chemical and natural detoxification processes. Total cyanide analysis is subject to interference from thiocyanate; some cobalt, gold, and platinum cyanide complexes may not be accurately measured.

It is important to note that universally reliable techniques and procedures for sampling and analyzing solid matrices for cyanide do not exist; however, research is progressing in this area (*23*). The need to determine cyanide species in solids, some of which are extremely transient when subjected to changes in temperature, pH, pressure, etc., has resulted in a profusion of sampling and analytical methods that are complex and cumbersome to use on a routine basis. Historically, there have been ambiguities in the analytical procedures used and the reporting of the cyanide species determined. Elimination of the uncertainty in cyanide analysis and reporting would require: (1) standardization of routine sampling and analytical procedures so that reliable cyanide values can be correlated to the solids, and (2) development and application of specific protocols detailing the type of sampling equipment, preservation procedures, and analytical methods.

Certain aspects of cyanide toxicity are well documented; however, the long-term stability of various cyanide complexes formed in the heap leach have yet to be adequately evaluated. A brief review of some fundamental facts about cyanide toxicity follow (*23*):

A toxicant is a chemical, physical, or biological agent which produces an undesirable or harmful effect upon a living organism; the level of toxicity measured is dependent upon the organism affected and the dosage and form of the toxicant.

Free cyanide is rapidly absorbed through ingestion and inhalation and passes into the bloodstream. Free cyanide can also be absorbed through the skin.

The lethal toxicity of free cyanide is associated with its high affinity to form strong bonds with iron in an enzyme that controls the cellular use of oxygen. Cyanide bonded to the enzyme inactivates the exchange and utilization of oxygen leading to cellular asphyxiation and tissue death.

Lethal levels of free cyanide for human adults are 1 to 3 mg/kg of body weight if ingested, 118 to 355 mg/m^3 if inhaled, and 100 mg/kg of body weight if absorbed through the skin (*18*). Concentrations of cyanide (HCN^- and CN^-) above 0.2 mg/L of water are fatal to most fish (*43*). To reach a lethal dose of 100 mg CN_F for a human weighing 110 lbs or 2 mg CN_F/kg of body weight, would require immediate consumption of 125 gallons of water containing 0.2 mg/L CN_F.

Cyanide is noncumulative, nonembryotoxic, and noncarcinogenic.

Cyanide occurs naturally in microorganisms, animals, and vegetation.

All forms of cyanide degrade naturally in the environment through a variety of processes including oxidation, photodecomposition, biodegradation, hydrolysis, volatilization, and adsorption.

Once free cyanide (HCN^-, and CN^-) forms another compound, its toxicity diminishes dramatically. Table B-1 also lists the relative stability of metal cyanide compounds in solution, in approximate order of increasing stability.

Determining the toxicity of cyanide solutions requires the evaluation of other parameters besides total cyanide concentration. Other parameters which affect the toxicity of cyanide solutions are temperature, pH, salinity, amount of dissolved oxygen, ammonia, cyanate, and thiocyanate, and the concentration of dissolved and suspended solids. Table B-2 summarizes the effects of dissolved oxygen, temperature, salinity, ammonia, and pH on the toxicity of cyanide solutions.

Table B-2—Effect of other parameters on cyanide solution toxicity

Parameter	Range	Effect on toxicity
Dissolved oxygen.	Less than 100% saturation.	Increases toxicity.
Temperature . .	From 6° C and 18° C.	Three-fold increase with 12° increase in temperature.
Salinity	9 to 17 parts per thousand.	Toxicity increases with increase in salinity.
Ammonia	0.35 to 0.70 mg/L NH_3.	More than doubles toxicity.
pH	Greater than 8.5 . .	Slight decrease in toxicity at higher pH due to minimized formation of HCN^-.

Source: (*33*).

REGULATORY BACKGROUND

With the growing consciousness of the public and various government regulatory agencies of the potential damage to water and air quality by industrial wastes, all industries, including mining, are facing increasing pressure to accept responsibility for rendering their wastes nontoxic. For cyanide heap leach facilities to properly satisfy State rules and regulations for operating permits, operators must ensure State regulators that solutions and solid wastes derived from their operation will not pose a threat to human health or degrade the environment. A justifiable basis for regulation of liquid and solid wastes at cyanide heap leach operations is from solid scientific knowledge. With this in mind, three specific conditions must exist before adverse impacts from cyanide to human health and the environment can occur: (1) a source of toxic or potentially toxic cyanide, (2) a pathway to transport the cyanide to an accessible environment, and (3) a receptor population (humans, fish, wildlife, etc.). Effective regulations based on scientific information would not overlook that at any given heap leach site all three of the above conditions may not exist, therefore, potential impacts will not exist.

REGULATIONS

Operators are generally required to submit a reclamation plan during the permitting stage, detailing how solutions and solids will be handled and neutralized or detoxified if required. All waste materials generated at the site, including waste rock and process-generated sludge, may be subjected to tests for acid generation potential, toxicity, and corrosivity. Additionally, some States require a cyanide degradation or neutralization study using a test heap or column leach test to prove that the leached material can be detoxified to meet standards specified in the permit. Detailed sampling programs of detoxified spent ore and solutions may also be required to prove that neutralization standards have been meet. A summary of State cyanide regulations and State agencies responsible for regulating cyanide heap leach facilities is included at the end of this appendix.

Existing State regulations generally require one of two approaches for meeting cyanide solution and solids neutralization standards:

(1) Some States require rigid adherence to applicable cyanide detoxification standards for process solutions, heap effluent, and process-related solids. Typically, detoxification criteria for cyanide solutions is based on the U.S.

Environmental Protection Agency's (EPA) recommended drinking water guideline of 0.2 mg/L total CN; however, some States may have nondegradation regulations.

(2) Some States evaluate and set cyanide detoxification standards on a case-by-case basis dependent upon site-specific characteristics and conditions.

Of the States which require adherence to strict water quality standards, compliance with nondegradation rules for ground water and surface water are the most difficult for operators to comply with. Typically, nondegradation rules require operators to adhere to site conditions that existed prior to activity or disturbance. Nondegradation standards are usually established for pH, metals, hardness, and turbidity in addition to standards for cyanide and any other processing chemical used at the site.

Setting detoxification requirements based on site specific conditions allows the regulator and operator flexibility in determining what standards are appropriate for a given site. From a mine operator's point of view this is the more equitable of the two approaches for establishing regulations because it is based on a scientific evaluation of the site conditions; however, it requires regulators to be knowledgeable in engineering, chemistry, geology, and hydrology. Site-specific characteristics appraised in case-by-case permit conditions usually include: (1) an evaluation of the toxicity of the wastes generated; (2) consideration of the beneficial use of ground and/or surface waters; (3) proximity to surface water, ground water, and human habitation; (4) stratigraphy; (5) precipitation-evaporation ratio; (6) climate; and (7) cyanide attenuating capacity of soils and leached materials.

STATE CYANIDE DETOXIFICATION REGULATIONS[2]

Regulatory officials from 15 States were questioned about their State's regulations concerning maximum residual cyanide concentrations in spent heaps. Table B-3 lists the States and the regulatory agencies contacted, and table B-4 summarizes the results of the survey.

[2]This section is based on A. Smith, and D. W. Struhsacker. Cyanide Geochemistry and Detoxification Regulations. Paper in Introduction to Evaluation, Design, and Operation of Precious Metal Heap Leaching Projects. ed. by Van Zyl, Hutchison, and Kiel. Soc. of Min. Eng. AIME, 1988.

Table B-3—Surveyed State agencies responsible for regulating heap leach operations

State	Organization
Alaska	Dep. of Environmental Conservation, (907) 465-2653.
Arizona	State Mine Inspector's Office, (602) 255-5971.
California	Southern Lahontan Region Water Quality Control Board, (619) 245-6583.
	Northern Lahontan Region Water Quality Control Board, (916) 544-3481.
	Colorado River Basin Region Water Quality Control Board, (619) 346-7491.
Colorado	Dep. of Natural Resources-Mined Land Reclamation Division, (303) 866-3567.
Idaho	Dep. of Health and Welfare Division of Environment Quality, (208) 334-5840.
Montana	Dep. of State Lands, (406) 444-2074.
Nevada	Dep. of Conservation and Natural Resources—Division of Environmental Protection, (702) 885-4363.
New Mexico	Groundwater Section New Mexico Environmental Improvement Division, (505) 827-2850.
North Dakota	Health Dep.—Water Supply and Pollution Control, (701) 224-2354.
Oregon	Dep. of Environmental Quality—Water Quality Division, (503) 229-5324.
South Carolina	South Carolina Land Resources Commission Division of Mining and Environment, (803) 758-2823.
South Dakota	Dep. of Water and Natural Resources, (605) 773-3151.
Utah	Div. of Environmental Health—Water Pollution Control, (801) 538-6146.
Washington	Div. of Geology and Earth Resources—Dep. of Natural Resources, (206) 459-6372.
Wyoming	Dep. of Environmental Quality, Water Quality Division, (307) 777-7781.

Table B-4.—Summary of State cyanide regulations

State	Cyanide regulations	Comments
Alaska	Draft regulations specify 0.2 mg/L WAD cyanide.	Regulations should be final in 1992. Standards apply to heap effluent, other standards for land application and tailings.
Arizona	0.2 mg/L free CN^-	State health standards only. Assume zero discharge. Discourage hypochlorite neutralization.
California Northern Region.	0.4 mg/L total CN^- 0.2 mg/L free CN^-.	Standards apply to remaining liquids in ponds, heaps, etc. Also have solids extraction test of less than 4.0 mg total CN^- /kg spent ore and less than 2.6 mg/kg free CN^-/kg spent ore.
Southern Lahontan Region	0.2 mg/L free CN^-	Standard applies to remaining liquids in ponds, heaps, etc. Also have solids extraction standard of 10 mg total CN^-/kg tailings.
Colorado River Basin Region	No specified standard (precedent of 10 mg/L free CN^- for Mesquite).	Statistical approach: 90% of at least 10 samples must contain less than 10 mg/L free CN^-; no sample can contain more than 20 mg/L free CN^-. Testing and sample procedures specified for 5:1 extraction performed on a 100 g sample of leached ore.
Colorado	No set standards (will be redrafting regulations).	Evaluate each site for quality of receiving surface and ground water. Emphasize zero-discharge design controls to ensure containment.
Idaho	Neutralization requirement based upon site characteristics expressed in terms of pH range or free and/or WAD cyanide. In 1991 considering redrafting.	Regulations do no specify universal CN^- standard. Will evaluate each site-proximity to surface water, quality of receiving water, etc. Regulations include bonding requirements.
Montana	No set standards (nondegradation rule).	Determined by quality of receiving water. Nondegradation implies a drinking water standard (0.2 mg/L free CN^-) if high-quality receiving waters. Permits could be more lenient for lined facilities with caps and diversions to prevent drainage into streams.
New Mexico	0.2 mg/L total CN^-	Not an effluent standard per se. Will take into consideration attenuation and dilution (i.e., can have more than 0.2 mg/L total CN^- in effluent). Oritz rinse test: 100 lb sample rinsed with 1 gal fresh water; filtrate must be less than 100 ppm free CN^-. Might accept this for other lined facilities.
Nevada	0.2 mg/L WAD cyanide	Evaluate each site for proximity to ground water, exemption to standard is possible if specific criteria are met. Spent ore rinse effluent must be less than 0.2 mg/L WAD cyanide and solids must meet meteoric water rinse test standards, if failed spent ore must be stabilized.
North Dakota	No set standards	No heap leach mines. Would probably impose surface water quality standards.
Oregon	Draft regulations specify heap effluent of 0.2 mg/L WAD cyanide and 10 mg/L total.	Spent ore standards for soluble cyanides, 0.2 mg/kg WAD and 2.5 mg/kg total as well as 10 mg/kg total CN after soluble cyanide extraction. 30-year post-closure monitoring.
South Carolina	No set standards (Haile precedent of 10 mg/L free CN^-).	Will evaluate each site. After closure, heaps at Haile will drain into stream with pH of 4 and elevated CN^- content.
South Dakota	State standard of 0.50 mg/L WAD cyanide.	Measured in effluent coming off of heap—any method of detoxification acceptable. Mean of several samples must be less than or equal to 0.50.
Utah	Not set standards (Mercur precedent of 5 ppm free CN^-.	Would look at Mercur permit as precedent, but not a standard. Require double-lined pads with leak detection system. Mercur uses permanent, expandable pads (i.e., heaps wasted in situ).
Washington	No set standards (in process of drafting regulations).	Will probably evaluate each site, no measurable CN^- allowed in effluent from reclaimed facilities.
Wyoming	0.02 mg/L free CN^-	Based on quality of receiving water, effluent can not exceed ambient water quality. Would be more lenient for zero-discharge facilities (i.e., if no surface or ground water impacts.

A wide diversity of responses was received in this survey. There is no consensus among the States surveyed concerning the cyanide species specified in the regulations or permit conditions. Some of the States express their cyanide requirements in terms of free cyanide, whereas others have standards defined in terms of total cyanide. Idaho includes WAD cyanide in its regulations. Some States also express neutralization requirements as a range of pH values in lieu of a specified cyanide level. No two States have identical regulations. However, some generalizations about the survey data can be made. Most States took one of the following approaches:

- Strict adherence to a universally applicable cyanide detoxification standard (generally the EPA-recommended drinking water guideline of 0.2 mg/L total cyanide);

- Establish permit conditions on a case-by-case basis depending on site-specific conditions.

In most States, cyanide neutralization criteria are specified in the "zero-discharge" water quality permit required to build and operate a heap leach facility. In addition to neutralization requirements, these permits also specify design, construction, operational, and monitoring criteria.

In evaluating a project and determining permit conditions, most of the States with experience in heap leach operations were more concerned with cyanide containment than with specific cyanide concentrations remaining in the heap. These States emphasize engineering parameters, such as liner specifications and hydrologic (flood control) design criteria. Some of the more experienced States also specify detailed procedures for heap rinsing, rinsate sampling, and analytical testing.

As shown on table B-4, some States are in the process of establishing or redrafting cyanide neutralization requirements for spent cyanided heaps. In most cases, this action has been prompted by the increasing number of permit applications for precious metal cyanide heap leach operations. The changing regulatory atmosphere is in direct response to the increasing use of heap leach techniques.

States adopting a drinking water guideline as their cyanide neutralization criterion generally do not have many active cyanide heap leach operations and thus do not have much direct experience with heap leach technology. In contrast, the States with several active cyanide heap leach projects have opted for the more site-specific approach, giving some flexibility in determining permit conditions.

States which consider site specificity in setting neutralization requirements and other permit conditions generally try to select reclamation procedures and neutralization and abandonment requirements appropriate for the project site. When site conditions are taken into consideration, it becomes apparent in many cases that it is impractical and unnecessary to impose drinking water guidelines on the rinsate from a detoxified heap. The environmental sensitivity of the project site may not warrant such stringent requirements. Furthermore, it may be costly, if not impossible, to neutralize to a drinking water guideline.

In several States a bonding authority governing heap leach projects is coupled with the regulations. Heap leach operators in these States are required to obtain a bond to cover the cost of rinsing and detoxifying the heaps. Release of this bond is tied to neutralizing the spent heaps to a specified standard.

An understanding of cyanide chemistry is a prerequisite to establishing realistic cyanide detoxification standards for abandoned heap leach projects. Environmental regulations should consider the self-neutralization potential of an inactive heap, the ephemeral nature of molecular hydrogen cyanide, and the environmental sensitivity of a given project. More stringent requirements should be reserved for projects with nearby downgradient fishable streams or sources of potable surface and ground water.

Application of a cyanide drinking water guideline on the rinsate from a neutralized heap is neither realistically achievable nor necessary in order to protect surface and ground water resources in most instances. Based upon a consideration of site conditions, including the attenuating properties of site subsoils and bedrock and the distance to the nearest surface water, it has been demonstrated that water quality guidelines are maintained for receiving waters when residual cyanide levels are allowed in the detoxified heaps.

As more heap leach mining permit applications are reviewed and processed by regulatory agencies, more changes in the regulatory environment affecting precious metal heap leach projects can be expected. With increased experience in heap leach operations and a broadening awareness of the short- and long-term effects of cyanide and the behavior of cyanide in the heap leach environment, the realistic site-specific approach to establishing cyanide neutralization requirements will become acceptable.

SUGGESTED READING

(Cyanide Detoxification Regulations)

Mudder, T. I. (ed.). The Attenuation and Migration of Cyanide in the Environment. Ch. in Chemistry, Analysis, Toxicity, and Treatment of Cyanidation Wastewaters. Pres. at Soc. Min. Eng. AIME Short Course, Las Vegas, NV, Feb. 26, 1989, pp. 3-1 - 3-75; available upon request from SME Meetings Dep., Littleton, CO.

Mudder, T. I. (ed.). The Toxicity of Cyanide and Related Compounds in Mining Wastewaters. Ch. in the Chemistry, Analysis, Toxicity, and Treatment of Cyanidation Wastewaters. Pres. at Soc. Min. Eng. AIME Short Course, Las Vegas, NV, Feb. 26, 1989, pp. 5-1 -5-37; available upon request from SME Meetings Dep., Littleton, CO.

Rouse, J. M. Cyanide and the Environment. Min. J. (London), v. 315, No. 8085, 1990, pp. 18-19.

Smith, A., and D. W. Struhsacker. Cyanide Geochemistry and Detoxification Regulations. Ch. in Introduction to Evaluation, Design and Operation of Precious Metal Heap Leaching Projects, ed. by D. J. A. van Zyl, I. P. G. Hutchison, and J. E. Kiel. Soc. Min. Eng. AIME, 1988, pp. 275-292.

APPENDIX C.—CYANIDE DETOXIFICATION METHODS

BACKGROUND

During closure, stabilization and detoxification of spent ore heaps are the primary concerns of operators and regulators at cyanide heap leach operations. Effective neutralization of spent ore heaps involves detoxifying cyanides that may have accumulated in solutions contained in rock voids, adsorbed onto ore particles, and diffused into the ore matrix. Major factors that influence heap neutralization techniques include heap geometry, liquid and gas permeability of the heap, and the chemistry and mineralogy of ore particles.

All heap detoxification processes are accomplished through the exposed surface area of the heap. The greater the ratio of heap surface area to tons of material, the higher the potential for natural and enhanced detoxification processes to occur (*15*). The amount of heap surface-area-per-ton (SAPT) of material on the leach pad is dependent on heap geometry. In many instances, geographic factors may limit the amount of area available to the operator for siting a heap. Heap SAPT values vary from 2 ft^2/st for small flat-lying tabular heaps to less than 0.1 ft^2/st for valley fill heaps covering 300 acres with 100-ft plus heights. Unfortunately, economic and operational dichotomies exist with SAPT values. In arid climates, operators attempt to lower the heap SAPT value to lessen process solution losses by evaporation and limit cyanide loss due to natural degradation processes. In areas with excessive snow or rainfall, operators attempt to avoid influxes to the solution distribution system by decreasing the amount of heap and pond surface area exposed to precipitation.

The more permeable the heap, the greater the potential for cyanide solutions to dissolve gold and silver from the ore as well as for cyanide detoxification processes to react within the heap. Heap permeabilities are controlled primarily by ore mineralogy, ore particle size distribution, and heap construction techniques. Heaps with relatively low permeabilities and low heap SAPT values will generally require aggressive detoxification-reclamation procedures such as physically disturbing the heap to increase permeability. Conversely, heaps with relatively high permeabilities and high SAPT values can generally be detoxified with passive methods of fresh water rinsing or by natural degradation.

Chemistry and mineralogy of the ore particles control rates and types of detoxification reactions that will occur within the heap. In some cases, detoxification chemicals may react more quickly with the ore on the heap than the cyanide compounds meant to be detoxified, thereby may increasing reagent cost. Some cyanide chemical bonds be stronger than the detoxification chemical's ability to break them.

Operators periodically are faced with the task of neutralizing leach solutions, heap effluent, and rinse solutions if they are in a net precipitation climate (precipitation exceeds evaporation), in an area with excessive seasonal precipitation, or face seasonal closure. In addition to detoxifying solutions for cyanides, consideration of pH, metals, and other inorganic and organic compound content, hardness, and turbidity must also be given before discharging fluids into the environment. Water quality discharge criteria are established by the appropriate regulatory agency and standards must be met for land application of solutions as well as discharge into tailings impoundments.

PROCESS CHEMICAL AND COST ACCOUNTING

In general, there is a lack of published information that accurately documents the effectiveness and cost of detoxifying cyanide leached heaps. However, there are a number of operating procedures, that if documented, would be informative and useful for determining the cost and practicality of utilizing various cyanide detoxification methods.

Before beginning detoxification of solutions or solids, determination of what kinds and amounts of cyanide (free, WAD, and total cyanide) are present would be useful. Comparison of the cyanide remaining in solution and/or in the heap to the amount of cyanide added to the system during leaching activities provides the operator with a basic knowledge of how much cyanide was lost due to natural degradation processes, dispersed due to reactions in the heap, or dissipated due to improper maintenance of solution chemistry. While the leach facility is operating, the amounts and types of reagents, including cyanide, lime, caustic, descaling agents, etc., added to the leach facility could be accounted for. An understanding of cyanide accounting provides the operator with valuable insight and information for future operations about leaching and detoxification reagent requirements. Knowledge of the amounts and types of cyanide in solutions and/or solids to be detoxified would also assist in determining the size and type of process(es) required for detoxification. Accounting during detoxification, showing actual neutralization methods used and reagents consumed for specific ore types and heap leaching practices would also provide the operator and environmental 83 regulators with valuable knowledge on what methods are successful and what costs will be incurred.

DETOXIFICATION METHOD SELECTION

There are numerous processes capable of detoxifying, to some degree, cyanide in spent ore heaps and process solutions; however, the more commonly used and environmentally acceptable methods are listed below:

(1) natural degradation,
(2) fresh water rinse,
(3) alkaline chlorination,
(4) hydrogen peroxide,
(5) SO_2 and air.

Nonchemical cyanide detoxification processes (e.g., natural degradation and fresh water rinsing) will react, to some degree, with cyanides entrapped in the heap, as well as with cyanides in the process solutions. The chemical methods listed above are more effective in detoxifying cyanides in solutions than cyanides contained in the heap. Therefore, it is standard practice to utilize these chemical detoxification processes to treat heap effluent, recycle the treated effluent onto and through the heap in a closed-circuit process, and to flush cyanides from the heap until detoxification requirements are met.

Discussion of each neutralization-detoxification procedure follows. Each discussion examines cyanide detoxification effectiveness, operational and environmental advantages and disadvantages, and a description of process component requirements.

Table C-1 compares the detoxification processes for cyanide neutralization effectiveness; potential for generating deleterious byproducts, whether reagent handling dangers exist; relative costs; and time requirements for completion of cyanide detoxification reactions.

Natural Degradation

Natural degradation of cyanide is a combination of physical, chemical, and biological processes including reactions with sunlight (photodecomposition, oxidation), bacteria (aerobic and anaerobic biodegradation, oxidation), air (oxidation), and materials in the heap (hydrolysis, volatilization, oxidation, adsorption). Natural degradation processes continuously react with cyanide, both in the heap and solution ponds. The degree and rate of natural degradation of cyanide in the heap is largely controlled by the mineralogy of the spent ore, type and amount of cyanide species present, available bacteria, and the permeability of the heap in conjunction with specific site conditions including altitude, temperature, and precipitation. The spent ore mineralogy controls what types and amounts of metals and compounds are available for chemical reactions. Generally, free cyanides naturally degrade more rapidly than WAD and total cyanides. Total cyanides are the slowest to naturally degrade. Before biodegradation begins, bacteria and a food source must be present. Heap permeability controls the amount of available oxygen for aerobic biodegradation and oxidation processes as well as the flow of solution through the heap. Altitude correlates to vapor pressure which primarily controls the rate of volatilization, the higher the altitude the lower the vapor pressure, and higher the volatilization of HCN^- from solution. High temperatures generally increase natural degradation process reaction rates. As precipitation falls on and then passes through the heap, it provides oxygen and water for other degradation processes and transports soluble compounds through the heap. To visualize what types of natural degradation processes occur in and around a cyanide heap leach, Smith and Struhsacker compiled a schematic showing geochemical conditions within the heap environment (fig. C-1) (*36*). Table C-2 lists the chemical equations referred to in figure C-1.

Some heaps and solutions, specifically those associated with agglomerated ores, may not naturally detoxify to meet most current permit standards. However, natural degradation can still be used as an intermediate process to substantially reduce cyanide concentrations prior to using chemicals or other processes to meet detoxification standards.

Table C-1.—General comparison of detoxification techniques for a cyanide heap leach

	Cyanide detoxification techniques				
	Natural degradation	Fresh water rinse	Chlori-nation	Hydrogen peroxide	Sulfite air
Cyanide destruction:					
Free (CN^-,HCN)	Yes	Yes	Yes	Yes	Yes
WAD	Yes	Yes	Yes	Yes	Yes
Thiocyanate (SCN^-)	No	No	Yes	No	Yes
Iron cyanides	No	No	No	No	Yes
Potential for deleterious byproducts.	No	No	Yes	No	Yes
Handling dangers	No	No	Yes	Yes	No
Reaction time requirements	H	M-H	M-L	L	L
Cost	L	L	L-M	M-H	H

H High.
L Low.
M Moderate.

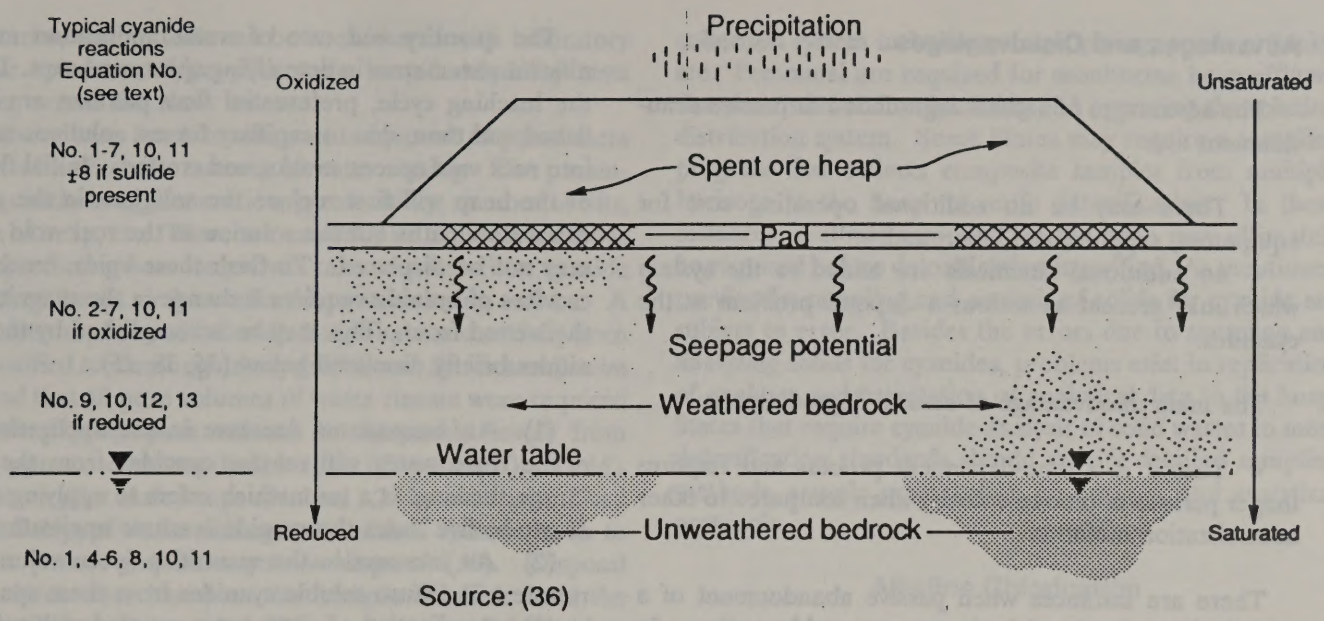


Figure C-1.—Prevailing geochemical conditions and typical cyanide reactions in the abandoned heap leach environment.

Table C-2.—Typical cyanide reactions in a heap leach environment

Hydrolysis

(1) $CN^- + H_2O \rightarrow HCN^- + OH^-$

Oxidation of HCN and CN^-

(2) $2HCN + O_2 \rightarrow 2HCNO$

(3) $2CN^- + O_2 + \text{catalyst} \rightarrow 2CNO^-$

Hydrolysis of CNO

(4) $HCNO + H_2O \rightarrow NH_{3(g)} + CO_{2(g)}$

Hydrolysis-Saponification of HCN

(5) $HCN + 2H_2O \rightarrow NH_4COOH$ (ammonium formate)

or

(6) $HCN + 2H_2O \rightarrow NH_3 + HCOOH$ (formic acid)

Aerobic biodegradation of HCN

(7) $2HCN + O_2 + \text{enzyme} \rightarrow 2HCNO$

(4) $HCNO + H_2O \rightarrow NH_3 + CO_2$

Thiocyanate formation

(8) $S_x + S^{2-} + CN^- \rightarrow S_{x-1} + CNS^-$

(9) $S_2O_3 + CN^- \rightarrow SO_3^{2-} + CNS^-$

Simple cyanide compound dissociation

(10) $NaCN \rightarrow Na^+ + CN^-$

Metal-cyanide complexation

(11) $Zn(CN)_2 + 2CN^- \rightarrow Zn(CN)_4^{2-}$

Anaerobic biodegradation of HCN and CN^-

(12) $CN^- + H_2S(aq) \rightarrow HCNS + H^+$

(13) $HCN + HS^- \rightarrow HCNS + H^+$

Source: (*36*).

Detoxification Efficacy

Due to the lack of documented studies, there are no accurate methods for predicting the amount of time required for a heap to detoxify by natural degradation. Engelhardt reported an 85% loss of free cyanide in a 13-ft high agglomerated heap over a 15-month period due to natural degradation processes and projected that it would require 4 years for the material in the heap to reach a free cyanide level of less than 1 mg/kg of spent ore (*11*). Annual precipitation in this area ranges from 3 to 7 in. In contrast, another agglomerated, 20-ft high heap, after being leached with 700 mg/L CN solution, had its effluent cyanide level drop to 0.03 mg/L total CN over a 13-month period which experienced more than 18 in. of precipitation (*15*).

Cyanides in the top 3 to 5 ft of a heap leach are most readily detoxified by natural processes. Therefore, sampling programs to verify detoxification, or to determine whether other methods should be used to enhance heap detoxification, should keep this in consideration. As mentioned previously, universally reliable techniques and procedures for sampling and analyzing solid matrices for cyanide do not exist.

Advantages and Disadvantages

The advantages of natural degradation or passive abandonment are:

- There may be no additional operating cost for equipment, supplies, and labor; and
- no additional chemicals are added to the system which may present as serious a disposal problem as the cyanides.

The main disadvantage of natural degradation is:

- That it is a time-dependent process and requires longer periods of time to detoxify when compared to other neutralization methods.

There are instances when passive abandonment of a cyanide heap leach might be an acceptable option. In areas with high evaporation-to-precipitation ratios, if an operator can prove that drained spent ore heaps will not generate runoff after precipitation, cyanide detoxification of the heaps may not be required. The reasons being: (1) there is no pathway available for transporting cyanide to an accessible environment, and (2) any cyanide remaining in the heap will eventually be detoxified by natural processes.

Cost Components

Daily monitoring of solution pond levels may be required if effluent drains into a pond that is not part of an operating solution distribution system. Effluent should be sampled on a minimum of a monthly basis to record progress of detoxification. A sampling program that collects composite samples from multiple horizons in the heap may be required to verify detoxification. Multiple samplings of the heap may ultimately be required before detoxification is verified.

Water Rinsing

Water rinsing of leach heaps essentially emulates and expedites the natural degradation processes related to precipitation. The degradation processes enhanced by water rinsing are hydrolysis, oxidation, and flushing of soluble cyanides from the heap. Heap detoxification by water rinsing is controlled primarily by the permeability of the heap, the chemistry of the rinse water, and the rate of application. Operators commonly water rinse heaps prior to decommissioning to flush remaining recoverable concentrations of soluble gold and silver cyanides from the ore.

The quantity and rate of water application are significant parameters in detoxifying spent ore heaps. During the leaching cycle, preferential flow patterns are established and then, due to capillary forces, solutions migrate into rock void spaces, cracks, and crevices. Initial flushing of the heap will first replace the solutions in the preferential flow paths but the solution in the rock void spaces may not be displaced. To flush these voids, cracks, and crevices of cyanide requires a change in the magnitude of the wetted front. This may be accomplished by the techniques briefly discussed below (*35*, *38*, *15*).

(1) An increase or decrease in the application rate of the rinse water will release cyanides from the heap. "Surge flushing" is a term which refers to applying rinsate at two to five times the cyanide leachate application rate.
(2) An increase in the quantities (pore volumes) of rinsate will diffuse soluble cyanides from these spaces.
(3) Application of rinse water coupled with sufficient time to allow the heap to "rest" or drain down towards the field capacity of the heap, repeated in cyclic patterns, will also reduce heap cyanide levels.

The chemistry of the rinse water is also an important factor to consider in water rinsing. The lower the pH of the rinse waters, the greater the ability to lower the pH (neutralize the buffering capacity) of leachate solutions entrapped in pore volumes in the heap. As the pH of the solutions in the heap decrease from a typical operating pH of 10.5, the greater the likelihood of cyanide ions (CN^-) reacting with water (hydrolyzing) and forming hydrogen cyanide (HCN^-). HCN^- has a very high vapor pressure and, once formed, rapidly volatilizes. As the pH of heap solutions drop below 9.36, the majority of the remaining CN^- will form into HCN^-. If an ore has been agglomerated with a lime-cement compound, the buffering capacity of the heap will be increased and it will take longer to reduce the pH in the heap and longer to hydrolyze CN^-.

As rinse waters are circulated through the heap, metals and cyanides accumulate in the solution. Use of fine spray or impact sprinklers (Rainbirds) for rinse water application are effective for the removal of the accumulated free and WAD cyanides by enhancing oxidation and volatilization processes. Fine spray sprinklers are also useful for evaporating excess process solutions.

Detoxification Efficacy

Operators can generally determine if water rinsing will efficiently detoxify spent ore during the initial metallurgical testing of the leaching parameters of the ore. To ascertain general information on water rinsing cyanide-leached

material, rinsing tests can be coordinated with laboratory scale column and/or pilot scale heap leachability tests using actual site rinse waters.

Every heap leach has its own unique set of parameters that will affect the success of water rinsing. The parameters include agglomeration, permeability, number of lifts, size of heap, etc. There are currently no accurate methods for predicting how long it will take to water-rinse cyanide leached heaps or how effective water rinsing will be. A number of pilot and full-scale heaps have successfully been detoxified to meet regulatory guidelines. Smith and Brown noted that 10 pore volumes of water rinsate were required to drop heap pore volume total cyanide levels from 133 ppm to consistently less than 0.2 ppm (*35*). Todd's work on pilot scale heaps of minus 1.25-in material showed that 5 days of water rinsing reduced free cyanide levels to meet permit requirements for disposal (*38*). Disposal standards were based on the analysis of solids from the heap (below 10 mg total CN per liter on a 5:1 liquid to solid extraction performed on 100 g of leached material). As noted earlier, changing the rinse water application rate from the cyanide leachate application rate, increasing the number of pore volumes of rinsate, and/or cyclic rinsing and heap drain down are effective methods for expediting natural degradation of cyanide leached heaps.

Water rinsing to enhance natural degradation processes may not sufficiently or totally detoxify some heaps, especially those with agglomerated ore, to meet current permit standards. In those instances, water rinsing is still an excellent preliminary step in reducing cyanide concentrations before using other detoxification methods.

Advantages and Disadvantages

The advantage of water rinsing is:

- In arid areas, water rinsing will enhance natural degradation processes and the additional volume of rinsate can readily be disposed of through evaporation without using chemicals.

The disadvantage of water rinsing is:

- In wetter areas, there is the possibility of generating large volumes of partially contaminated rinse waters that are unacceptable for discharge to the environment without some means of chemical detoxification.

Cost Components

For water rinsing, an adequate quantity of fresh water is required as well as a rinse water distribution and collection system including pumps, piping, ponds or tanks, etc. Personnel are required for monitoring heap effluent characteristics and maintaining and operating the solution distribution system. Some States may require a sampling program that collects composite samples from multiple horizons in the heap to verify detoxification. In these instances, multiple samplings of the heap may ultimately be required before detoxification is verified. As mentioned previously, sampling and analysis of solids for cyanide are subject to error. Besides the errors due to sampling and analyzing solids for cyanides, problems exist in replication of analyses and correlation of analytical data to the heap. States that require cyanide analysis of solid wastes to meet detoxification standards should specify detailed sampling methods, sample preservation procedures, and analytical protocols.

Alkaline Chlorination

Historically, chlorination has been the most popular chemical process for destroying cyanide compounds. For over 35 years, chlorination has been used to detoxify cyanide in metal plating wastes and mineral processing effluent (*43*).

Process Chemistry

Chlorination, sustained to completion under alkaline conditions, destroys cyanide by oxidation in two stages (*32*). In the first stage, cyanide is oxidized and hydrolyzed to cyanate in less than 5 min at a minimum pH of 10.5 as shown:

$$NaCN + Cl_2 \rightarrow CNCl + NaCl.$$

$$CNCl + 2NaOH \rightarrow NaCNO + NaCl + H_2O.$$

Cyanide complexed with metals such as Zn, Cu, Cr, and Cd are also oxidized during this first stage of the process as shown for the zinc cyanide complex:

$$Na_2Zn(CN)_4 + 10NaOH + 4Cl_2 \rightarrow 4NaCNO + 8\,NaCl + Zn(OH)_2 + 4H_2O.$$

The second stage of the alkaline chlorination process, which may take as long as 2 h for complete reaction, oxidizes cyanate to nitrogen and carbon dioxide or bicarbonate at a pH above 8.5 as shown:

$$3Cl_2 + 2NaCNO + 6NaOH \rightarrow 2NaHCO_3 + N_2 + 6NaCl + 2H_2O.$$

Detoxification Efficacy

Alkaline chlorination can be used to detoxify cyanide in heap leach process solution ponds as well as cyanides in the solution remaining in the spent ore heaps. If the process is monitored, maintained properly, and allowed to proceed to completion, all free, WAD, and total cyanides, with the exception of iron cyanides, will be destroyed. Free cyanide is oxidized quickly with chlorine, as is thiocyanate. Cyanides complexed with gold, silver, cobalt, and nickel are the most difficult to oxidize. The proper design and efficient operation of a cyanide heap leach facility should effectively remove all gold and silver cyanides from the heap and solutions before detoxification begins.

Advantages and Disadvantages (*29*)

The advantages of using alkaline chlorination are:

- It is a well-proven and documented method for destroying cyanides.
- Capital outlay for equipment is low.
- It is effective at ambient temperatures and pressures.
- Process can be automated.
- Includes simple process components that allow for modular design; components are readily amendable for capacity expansion if needed.
- Heavy metals form hydroxides and metal concentrations can be effectively reduced to <1.0 mg/L.

The disadvantages of alkaline chlorination are:

- Ferro and ferricyanides are not treated, and there is difficulty treating nickel and cobalt cyanides.
- Potential exists for leaving toxic levels of chloramine and excess chlorine in solution that require removal by SO_2 or SO_3 treatment.
- Requires careful control of pH to prevent formation of cyanogen chloride, which is very toxic. At pH levels below 10, cyanogen chloride is generated and chlorine consumption increases substantially.
- Chlorine gas and hypochlorite salts are toxic chemicals and potential hazards exist when shipping and handling these substances.
- Alkaline chlorination is not selective; therefore, it is subject to reaction with other substances in the waste stream which can lead to high chlorine consumption and reagent cost, e.g., 1 lb Cu requires 0.5 lb additional Cl_2; 1 lb Ni demands 2.2 lb Cl_2.
- Process generates substantial quantities of NaCl (salt) which may prohibit land application or disposal of solutions.
- Cyanide is not recoverable.

Cost Components

Alkaline chlorination of cyanide wastes can be accomplished by either batch or continuous processing methods. In both processes, the principles involved are identical, except the continuous process requires sufficient retention capacity in the reaction tanks to allow time to complete the reactions.

In most instances, process equipment at the site can be adapted and used to treat cyanide wastes. Figure C-2 schematically portrays the process equipment setup. An equipment list follows:

(1) bulk storage for lime or caustic,
(2) tankage for dissolving solid lime or caustic into solution,
(3) alkali resistant reagent feeder for metering alkali solution,
(4) bulk storage for chlorine liquid or solid,
(5) chlorinator for dispensing liquid chlorine or a reagent feeder for dispensing solid chlorine,
(6) reaction and treatment tank,
(7) agitator or pump to mix contents in reaction tank,
(8) miscellaneous piping, valves, and pumps as required,
(9) instrumentation [pH and oxidation reduction potential (ORP) meters and chlorine analysis].

Chlorine requirements are dependent on the amount of oxidizable compounds present that react with chlorine before the cyanides. Chlorine consumers include organic material, sulfur compounds (thiocyanate, thiosalts, etc.), and reduced metals (*32*).

Laboratory-scale column rinse tests will provide basic reagent requirements for alkaline chlorination of cyanide; however, correlation to the actual amount of reagents required for detoxification is tenuous at best. Ideally, 6.83 lb of chlorine are required to completely destroy 1 lb of total cyanide waste; however, up to 24 lb of chlorine per pound of total cyanide have been required when excessive amounts of chlorine consumers are present. Average chlorine consumption for complete cyanide destruction varies between 7 to 12.5 lb of chlorine per pound of total cyanide waste. Caustic soda or lime requirements to maintain system pH above 8.5 is also system-dependent and can vary between 0.8 to 7.3 lb per pound of total CN for complete cyanide destruction. If detoxification requirements are specified in terms of cyanate (CNO^-), the reagent requirements for theoretical oxidation of cyanide to cyanate are 2.7 lb of chlorine and 3.1 lb of caustic soda per pound of cyanide.

Chlorine is available in three forms. Liquid chlorine with 100% available chlorine has the lowest reagent cost

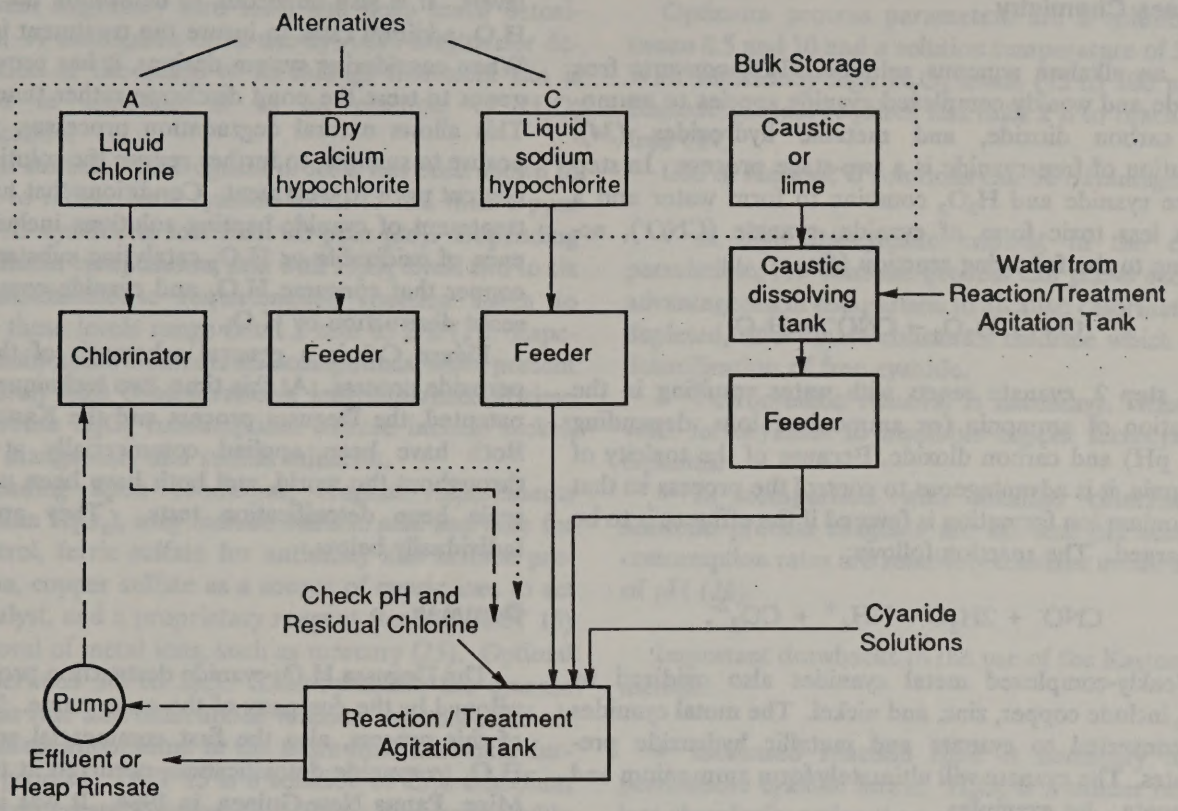


Figure C-2.—Alkaline chlorination process schematic.

of the three forms but the largest cost for equipment (cylinders, regulators, chlorinators, high pressure fittings, and piping). Liquid sodium hypochlorite, with up to 16% available chlorine, requires less equipment but is more expensive than liquid chlorine. Solid calcium hypochlorite has up to 70% available chlorine and is less costly, more stable, and easier to handle than liquid sodium hypochlorite. Price quotes from suppliers are readily available.

SUGGESTED READING

(Alkaline Chlorination)

Mudder, T. I. (ed.). Alkaline Chlorination. Sec. in The Chemistry, Analysis, Toxicity, and Treatment of Cyanidation Wastewaters. Pres. at Soc. Min. Eng. AIME Short Course, Las Vegas, NV, Feb. 26, 1989, pp. 3-1 - 3-75; available upon request from SME Meetings Dep., Littleton, CO.

Palmer, S. A. K., M. A. Breton, T. J. Nunno, and N. F. Surprenant. Alkaline Chlorination. Ch. in Metal/Cyanide Containing Wastes, Treatment Technologies. Noyes Data Corp., 1988, pp. 602-624.

Ritcey, G. M. Alkaline Chlorination. Sec. in Tailings Management, Problems and Solutions in the Mining Industry. Elsevier Sci. Publ., 1989, pp. 617-627.

Hydrogen Peroxide

Hydrogen peroxide (H_2O_2) is widely used for destruction of cyanide in mill tailings but the application of this process to cyanide heap leach dump detoxification is still largely under development. Application of this method to individual situations requires considerable preparatory testing to determine the character of the material to be treated and potential problems that may interfere with treatment.

Chemical companies are presently conducting studies at specific sites to determine process limitations and how they may be overcome. These studies have identified several requirements essential to successful cyanide heap detoxification using H_2O_2 (*14*). The most crucial finding has been that H_2O_2 treatment of heap effluent is more efficient and preferable than applying H_2O_2 solutions directly to the cyanide-bearing heap leach material. Treating heap effluent and other cyanide-bearing solutions in tanks or ponds insures that the contained peroxide is not exposed to H_2O_2-decomposing substances prior to reaching the site of cyanide contamination. Directly treating cyanide solutions reduces H_2O_2 consumption and costs.

Process Chemistry

In an alkaline aqueous solution, H_2O_2 converts free cyanide and weakly-complexed cyanide species to ammonia, carbon dioxide, and metallic hydroxides (*34*). Oxidation of free cyanide is a two-stage process. In step 1, free cyanide and H_2O_2 combine to form water and a much less toxic form of cyanide, cyanate (CNO^-), according to the following reaction (*5*):

$$CN^- + H_2O_2 \rightarrow CNO^- + H_2O.$$

In step 2, cyanate reacts with water resulting in the formation of ammonia (or ammonium ions, depending upon pH) and carbon dioxide. Because of the toxicity of ammonia, it is advantageous to control the process so that ammonium ion formation is favored if the effluent is to be discharged. The reaction follows:

$$CNO^- + 2H_2O \rightarrow NH_4^+ + CO_3^{2-}.$$

Weakly-complexed metal cyanides also oxidized by H_2O_2 include copper, zinc, and nickel. The metal cyanides are converted to cyanate and metallic hydroxide precipitates. The cyanate will ultimately form ammonium and carbonate. An example:

$$2Cu(CN)_3^{2-} + 7H_2O_2 + 2OH^- \rightarrow 6CNO^-$$

$$+ 2Cu(OH)_2 + 6H_2O.$$

For ferricyanide removal, soluble copper salts are added which form an insoluble cuproferricyanide precipitate (*14*).

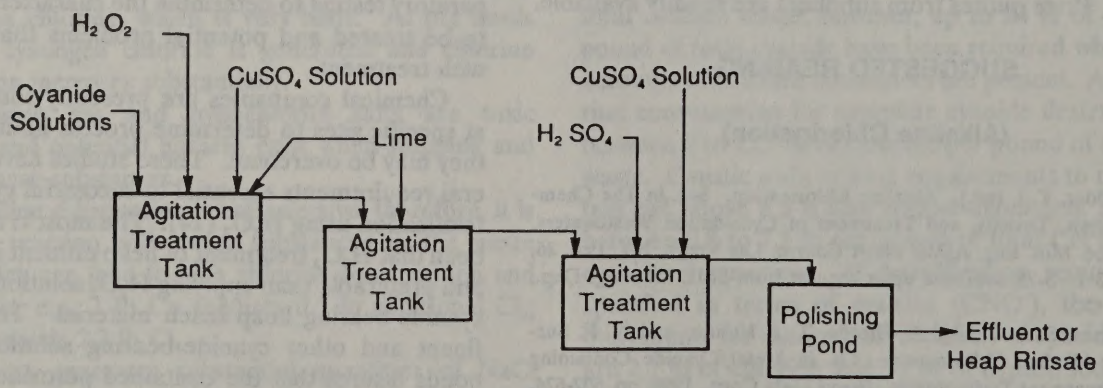
H_2O_2 treatment requirements include the ability to achieve slightly alkaline pH conditions, proper mixing of H_2O_2 and other reagents in the solutions to be treated, and sufficient reaction time to achieve the desired cyanide levels. It is also important to determine the appropriate H_2O_2 addition rates to insure the treatment is successful. When considering system designs, it has proven advantageous to treat the pond discharge rather than the inflow. This allows natural degradation processes, such as exposure to sunlight, to further reduce the solution's cyanide content prior to treatment. Conditions that hamper H_2O_2 treatment of cyanide-bearing solutions include the presence of oxidizable or H_2O_2 catalyzing substances such as copper that consume H_2O_2 and cyanide compounds that resist destruction by H_2O_2.

Figure C-3 is a general schematic of the hydrogen peroxide process. At this time, two techniques have been patented, the Degussa process and the Kastone process. Both have been applied commercially at gold mills throughout the world, and both have been used for full-scale heap detoxification tests. They are described individually below.

Degussa

The Degussa H_2O_2 cyanide destruction process was developed by the company of the same name. The first use of this process, also the first commercial application of H_2O_2 to cyanide detoxification, occurred at the OK Tedi Mine, Papua New Guinea, in 1984. It was used to treat cyanide and base metal ion levels in a flotation tailings stream. The mill tailings were being disposed directly into a nearby river and the Papua New Guinea Government was concerned about the potential impact on downstream water users. As a result of this treatment, not only cyanide but dissolved zinc and copper were reduced to allowable levels (Knorre, 1984).

Subsequently, the Degussa process has been shown to have broad applications. It has been used by other gold mills to treat cyanide in the liquid portion of tailings streams, barren pond bleeds prior to reuse, tailings ponds



Source: Modified from (14)

Figure C-3.—Hydrogen peroxide process schematic.

to prevent migratory bird kills, and heap leach detoxification. A description of its use by ACH-Dayton for detoxification of the heaps at its tailings treatment site is included in appendix B as an example of H_2O_2 detoxification.

When suitable, the Degussa process has been shown to be able to reduce total cyanide levels to less than 1 ppm and WAD cyanide to less than 0.5 ppm (*26*). Depending upon influent composition, and with H_2O_2 levels two to six times stoichiometric requirements, reaction times to achieve these levels range from 5 min to 2 h (*1*). Especially troublesome elements and compounds, when present in relatively high concentrations, lengthen reaction time and increase H_2O_2 consumption. These include nickel, copper, manganese, and sulfide minerals.

Depending upon conditions, reagent requirements (other than H_2O_2), may include sulfuric acid and lime for pH control, ferric sulfate for antimony and arsenic precipitation, copper sulfate as a source of cupric ions to act as a catalyst, and a proprietary reagent (termed TMT 15) for removal of metal ions, such as mercury (*25*). Optimal pH is between 9.0 to 10.5. This optimizes the cyanate hydrolysis rate and determines whether the contained nitrogen forms ammonium or the more toxic ammonia during this process. TMT 15 is a solution of 15% trisodium salt of trimercaptotriazine that forms highly insoluble metallic salts. Once formed, the metallic salts can be removed through solution treatment in settling ponds.

Kastone

The Kastone process, developed by E.I. du Pont de Nemours & Co. (Inc.), has been tested at the pilot plant level by the Homestake Mining Co. at its Lead, SD mine and at the Giant Yellowknife Mine in Northwest Territories, Canada (*6*). At the Giant Yellowknife Mine, effluent from a carbon leach plant was successfully treated for 3 months in a continuous pilot plant. The effluent, reclaimed from a barren solution pond, was treated and monitored through use of pH and copper- and cyanide-specific ion electrodes. Success of the pilot test prompted adoption of the Kastone process for cyanide detoxification at this site, replacing the use of alkaline chlorination. The full-scale plant will utilize components from the existing three-stage, alkaline chlorination facilities.

When prepared, the Kastone solution is a colorless liquid, miscible in water in all proportions. The specific reagent mixture, called Kastone B Peroxygen Compound, includes 41% to 50% H_2O_2, 5 to 10 mg/L formaldehyde, and 5 mg/L cupric copper (*10*, *22*). Formaldehyde is an activator in the cyanide oxidation process, whereas copper acts as a catalyst. Thus, both promote cyanide destruction.

Optimum process parameters are a solution pH between 8.5 and 10 and a solution temperature of 30° C (*22*). With sufficiently high H_2O_2 levels (75 to 100 mg/L), the Kastone process requires less than 2 h to reach 0.2 mg/L free CN.

Use of Kastone B solutions can be advantageous when:

- A high thiocyanate content in the effluent is permissible, the Kastone process can prove economically advantageous in comparison to alkaline chlorination. Until depleted, thiocyanate consumes chlorine which precludes detoxification of free cyanide.
- Ferrocyanide removal is necessary. Kastone converts ferrocyanide to insoluble copper ferrocyanide precipitates.
- In comparison with alkaline chlorination, the Kastone process reagents are far less pH sensitive and consumption rates are relatively constant under a variation of pH (*10*).

Important drawbacks to the use of the Kastone process include:

- Increased reaction time is necessary to achieve permissible cyanide levels. H_2O_2 is a milder oxidant and less chemically active than chlorine compounds.
- Presence of copper ion levels exceeding 100 ppm catalyzes H_2O_2 decomposition, resulting in increased H_2O_2 consumption and higher cost (*10*).

Detoxification Efficacy

Under proper conditions, H_2O_2 treatment has demonstrated to be one of the most effective methods for detoxifying cyanide-bearing solutions. H_2O_2 treatment applicability is being continually extended as experience is gained through experimentation and site-specific studies. It is expected that within the next several years H_2O_2 utilization for detoxifying cyanide leached heaps will be more clearly defined.

Perhaps one of the most important factors which may indicate the suitability of H_2O_2 detoxification techniques (or any detoxification technique) will be its acceptance by regulators. When considering site reclamation plans, agencies, such as the EPA and State environmental offices, are likely to prescribe the actual detoxification methods used. The criteria that will have the greatest impact on State and Federal regulatory agencies will be the short- and long-term effectiveness and environmental impact of prospective treatment methods. Based on these considerations, H_2O_2 techniques have an advantage. By far, the most frequently cited advantage for the H_2O_2 process is

the lack of introduction of toxic substances into the waste stream. Excess H_2O_2 readily hydrolyzes to water and oxygen. There is some concern over the formation of ammonia during the process, but this can be eliminated with proper pH maintenance.

Claims for actual treatment effectiveness in reduction of cyanide to permissible levels are somewhat uncertain. In general, it is stated that cyanide reduction through use of H_2O_2 can achieve recommended drinking water guidelines (0.2 mg CN_T/L) if enough H_2O_2 is injected into the waste stream and if enough reaction time is allowed. However, as cyanide detoxification requirements decline, H_2O_2 consumption increases significantly. As an example, it may require addition of as much H_2O_2 to reduce total cyanide levels from 50 to 1 ppm as it does to reduce levels from 500 to 50 ppm (*14*). The presence of certain cations and oxidizable material may also make current H_2O_2 techniques economically impractical.

More strongly bound cyanide-metal complexes, chiefly ferricyanides, are not removed by H_2O_2 treatment. Thiocyanate (SCN^-), a product of the reaction of cyanide and sulfide minerals, is also unaffected. Removal of these compounds requires a further processing step. Because of their chemical stability, however, removal of these compounds is considered important only when total cyanide levels are being monitored (*14*).

Advantages and Disadvantages

The advantages of using H_2O_2 are:

- Under optimum conditions, the process is relatively easy to use, requires relatively unsophisticated equipment, and allows imprecise operational conditions.
- Does not result in the addition of pollutants to the effluent stream. If excess H_2O_2 exists following treatment, it readily decomposes to oxygen and water, both of which have little impact on the surrounding environment.
- Does not result in release of poisonous gases such as chlorine.
- Can be carried out under alkaline conditions, thus it does not promote oxidation of sulfides and dissolution of contained heavy metals.
- Results in the formation of insoluble metallic hydroxides which can then be removed from the waste stream.

The disadvantages of using H_2O_2 are:

- Although the process can be modified to treat effluent streams containing thiocyanate and strongly complexed metallic cyanides, costs for H_2O_2 and other reagents to accomplish this may be prohibitively high.
- As with all other chemical processes, it requires care in handling asmishandling can result in potential health risks to personnel exposed in any manner to H_2O_2.
- Presence of certain cations in treated solutions, specifically nickel, will decompose H_2O^2, resulting in high consumption.

Cost Components

As noted above, one of the principal advantages of H_2O_2 treatment of cyanide waste is its simplicity. In most instances, process equipment at the site can be adapted and used to treat cyanide wastes. Existing facilities such as ponds and leach solution distribution and collection systems, can readily be adapted for treatment of heap detoxification effluent. Utilization of existing site environmental safeguards, such as fencing and netting, will also reduce costs. Thus, additional equipment requirements for heap treatment prior to abandonment is minimal. Process equipment requirements include:

(1) bulk storage for H_2O_2,
(2) H_2O_2 dosing equipment,
(3) bulk storage for lime or caustic and other reagents,
(4) tankage for dissolving solid lime or caustic into solution,
(5) alkali resistant reagent feeder for metering alkali solution,
(6) reagent feeders,
(7) reaction and treatment tank
(8) agitator or pump to mix contents in reaction tank,
(9) miscellaneous piping, valves, and pumps as required,
10) instrumentation (pH and ORP meters and cyanide analysis).

H_2O_2 is generally supplied in 4,000-gal containers. These dedicated specialty tanks, used for storage, are reinforced with steel girders and are designed to be trucked to the site and offloaded until the H_2O_2 is consumed. This is also prudent from a safety standpoint, as transfer of H_2O_2 is not without some risk should the fluid become contaminated. Dosing equipment, which determines the H_2O_2 flowrate and contains probes to determine cyanide levels, are also available from H_2O_2 manufacturers. Storage tanks and dosing equipment are available from H_2O_2 manufacturers at relatively modest rental fees or they may be purchased outright.

Operating costs are dominated by the cost for H_2O_2. In 1989, it was reported that this single reagent is "... at least 80% of total fixed and variable operating costs ..." (*14*). The remaining charges for other reagents, maintenance,

operating labor and supervision, depreciation, and interest charges have little impact. The previous statement was predicated on H_2O_2 detoxification of cyanide-bearing mill effluent and not heap leach detoxification. It is to be expected that reagent costs for detoxifying heap leach effluent would be similar to detoxifying mill effluent. However, because of anticipated changes in the heap effluent composition, it is expected that engineering and operating charges would increase considerably.

SUGGESTED READING

(Hydrogen Peroxide Process)

Comba, P. G., and S. L. McGill. Rinsing of Spent Precious Metal Ores for Heap Leach Decommissioning. 1990, 13 pp.; available upon request from P. G. Comba, BuMines, Reno Research Center, Reno, NV.

Mudder, T. I. (ed.). The Copper Catalyzed Hydrogen Peroxide Process. Sec. in The Chemistry, Analysis, Toxicity, and Treatment of Cyanidation Wastewaters. Pres. at Soc. Min. Eng. AIME Short Course, Las Vegas, NV, Feb. 26, 1989, pp. 6-87 - 6-97; available upon request from SME Meetings Dep., Littleton, CO.

Smith, A. Cyanide Degradation and Detoxification in a Heap Leach. Ch. in Introduction to Evaluation, Design and Operation of Precious Metal Heap Leaching Projects, ed. by D. J. A. van Zyl, I. B. G. Hutchinson, and J. E. Kiel. Soc. Min. Eng. AIME, 1988, pp. 293-305.

Sulfite-Air

The sulfite (SO_2)-air and hydrogen peroxide processes have largely supplanted alkaline chlorination for detoxification of cyanide in mill tailings. Scott (1989) reports that of the Canadian mills that use cyanide and treat effluent with an oxidizing agent, one-half use hydrogen peroxide and one-half use SO_2-air processes. The SO_2-air process is also suitable for detoxifying clarified cyanide waste streams and recently has also been shown to be applicable for heap leach detoxification (*8*).

Process Chemistry

In alkaline aqueous solution, WAD cyanide, in the presence of a copper catalyst, is neutralized to cyanate (CNO^-) by addition of sulfite chemicals. In some instances, air is sparged through agitated tanks to increase solution oxygen content. The basic chemical reaction is represented in the following chemical equation (*23*):

$$CN^- + SO_2 + O_2 + Cu + H_2O \rightarrow CNO^- + Cu + H_2SO_4.$$

Approximately 10% to 20% of the thiocyanate (SCN^-) present will also react directly with sulfite to form cyanate (CNO^-), although this reaction is inhibited until all free cyanide and weakly complexed metallic cyanide ionic forms are removed (*22*).

If solution neutralization criteria are based on total cyanide values and further thiocyanate reduction is necessary, the waste stream can be further treated once the more readily dissociable cyanide compounds have been removed. A copper catalyst is not required in this reaction as shown (*29*):

$$SCN^- + 4SO_2 + 4O_2 + 5H_2O \rightarrow CNO^- + 5H_2SO_4.$$

Cyanate (CNO^-) produced in the above reactions is hydrolyzed to form ammonium (NH_3) and carbon dioxide (CO_2) as shown previously in the H_2O_2 (hydrogen peroxide) detoxification section. Excess metallic ions in solution, resulting from metallic-cyanide ion dissociation, precipitate as hydroxides and form sludge in the reaction tank.

It is also feasible to use the SO_2-air process for total cyanide removal (*30*). To accomplish this, however, auxiliary reactions which first reduce ferricyanide to ferrocyanide then form a cuproferrocyanide precipitate, must occur. Thus, copper ions have a dual role in the SO_2-air process; to catalyze cyanide neutralization and to react directly with the more stable iron cyanide salts (as shown in the equations below) to form precipitates which eventually settle out as sludge (*23*).

$$2Fe(CN)_6^{-3} + SO_2 + 2H_2O \rightarrow 2Fe(CN)_6^{-4} + 4H^+ + SO_4^{-2}.$$

$$2Cu^{+2} + Fe(CN)_6^{-4} \rightarrow Cu_2Fe(CN)_6.$$

Reagent Requirements

Process reagent requirements are best determined by laboratory testing. Each site has atypical properties that will affect process kinetics in different ways and, when coupled with discharge criteria, require a unique blend of process reagents. Therefore, the reagent requirements listed below should only be considered as guidelines:

- SO_2 consumption rates range from 1 to 3 times the level predicted stoichiometrically (*8*). The calculated stoichiometric requirements are 2.47 parts SO_2 per part total cyanide (*9*).
- Consumption of copper sulfate is dependent upon the amount of dissolved cuprous copper in the solutions to

be treated. If 50 mg/L copper of solution are present, no further addition is necessary. Soluble copper use rates, if required, range from 0.04 to 0.30 parts copper per part total cyanide.

- The optimal process pH is 9; however, solutions can be successfully treated within the pH range of 8 to 10. Outside of this range process rates decrease, making the method impractical. Control of pH is generally achieved by addition of slaked lime; use levels generally range from 4 to 9 parts slaked lime per part total cyanide present.
- Residence times as low as 5 min have been reported for cyanide oxidation (*22*). Elsewhere, time required for this reaction has ranged from 10 to 60 min. When total cyanide is a discharge criterion, longer residence times and multistage reaction tanks will usually be required to remove thiocyanate and ion cyanide compounds.
- The presence of troublesome cations, such as antimony, may also complicate treatment by requiring additional stages.
- The sulfite-air process is temperature dependent; it proceeds rapidly at 25° C, whereas at 5° C it is not only markedly slower, but results in less complete removal of cyanic compounds (*22*).

SO_2-Air Methods

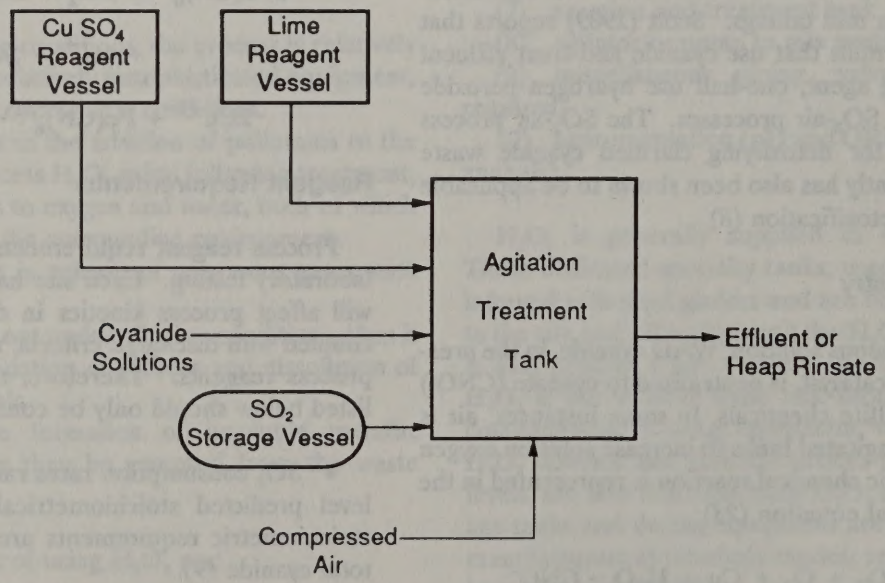
Currently, there are two patented SO_2-air methods, the International Nickel Co. (INCO) process and the Noranda process. The processes are similar; however, the Noranda method does not sparge the solution with air (*12, 29*). Both processes were initially developed in the early 1980's to treat effluent from mills using cyanidiation to recover gold and silver. To date, the INCO method has proven to be of greater commercial success. Figure C-4 is a schematic of this process. The Noranda method has been successfully tested at the Golden Giant Mine in Ontario. To date, the general lack of relevant information makes it difficult to include specific operational descriptions of this process.

Detoxification Efficacy

Unlike other oxidation techniques, the SO_2-air process initially reduces free and weak metallic ion cyanide compounds. It has little effect on the generally more prevalent but far less toxic thiocyanate (*20*). This tendency, the resultant reduction of reagent consumption, and cost makes it especially suitable where the effluent criteria measured is WAD cyanide.

Operational data from this process have largely been gauged in terms of total cyanide removal. Mill effluent is typically reduced from 200 to 400 ppm total cyanide to as little as 0.2 ppm total cyanide (*8*). It is assumed that WAD cyanide contained in these treated solutions would be substantially less than 0.2 ppm.

Inference from operational data of carbon-in-pulp (CIP) and carbon-in-leach (CIL) mill facilities suggests that the SO_2-air process has distinct advantages, primarily



Source: Modified from (8)

Figure C-4.—Sulfite-air process schematic.

minimal cost and universal effectiveness. It can be assumed that these advantages will be also demonstrated when heap leach detoxification is considered. As in use of the other techniques, however, this method may prove unsuitable at specific mines. Although past SO_2-air treatment of tailings slurries has shown that this technique is insensitive to entrained solids, the necessity to closely monitor and correct the reaction pH suggests that it is inadvisable to consider applying the treatment solutions directly to the heap. Therefore, fresh water or detoxified solutions will be applied to the heaps and the resultant effluent will be treated in a single or series of reaction tanks depending upon the number of treatment stages required.

Advantages and Disadvantages

The advantages and disadvantages of the SO_2-air process tabulated below have been abstracted from several sources, chiefly (*22*) and (*23*). Weighing the significance of each as an asset or liability for heap leach detoxification is dependent upon continued development of the process. The advantages of the SO_2-air process include:

- Of all chemical oxidation techniques compared, SO_2-air has the potential of being the least expensive.
- The process is capable of treating all cyanide forms common in mine waste streams.
- It preferentially treats the highly toxic free and WAD cyanide compounds initially rather than the less toxic more stable species such as thiocyanate.
- Presence of solids does not increase reagent consumption dramatically; therefore, the process is capable of treating both slurries and clear liquid waste streams.
- Characterized by low treatment times.
- It is relatively unaffected by the presence of sulfide or oxide minerals in the waste stream.

The disadvantages of the SO_2-air process include:

- The process generates relatively large amounts of sludge which, due to its metal content, may well be considered hazardous under certain regulations and require disposal under fairly stringent guidelines.
- The process-generated sludge, primarily the result of deacidification, will interfere with pH control if not removed, thus increasing treatment costs.
- Direct process application to heap leach piles (instead of heap effluent) is not widespread and therefore the implementation technology and its limitations are theoretical.
- The process is pH sensitive and is less effective under cool temperatures.
- Operating costs can include substantial royalty payments based on sulfite consumption.

Cost Components

Although multiple tank systems were typical of early SO_2-air systems, more recently single-tank systems have been characteristic. In most instances, process equipment at the site can be adapted and used to detoxify cyanide wastes. Existing facilities, such as ponds and leach solution distribution and collection systems, can be readily adapted for SO_2-air treatment at heap leach facilities. Utilization of existing site environmental safeguards, such as fencing and netting, will also reduce costs. Thus, additional equipment requirements for heap treatment prior to abandonment is minimal. Process equipment requirements for SO_2-air systems include:

(1) reaction tank,
(2) agitator and motor,
(3) air compressor,
(4) copper sulfate reagent vessel,
(5) lime reagent vessel,
(6) SO_2 storage tank,
(7) cyanide and pH instrumentation,
(8) oxygen level probe,
(9) piping.

In general, more than one-half of the operating cost of a treatment facility is the cost of sulfite. Sulfite is available in many forms. The most readily available forms include sulfide roaster offgases, burning elemental sulfur, liquid SO_2, and solid sodium bisulfate and sodium metabisulfite. Although operational factors may determine the form used, costs vary substantially. For example, an elemental sulfur plant can provide sulfite at $0.03/lb, liquid SO_2 can be obtained for $0.09/lb, and metabisulfite for $0.30/lb. The royalty paid to INCO for use of the process varies with the installation and is based on a variable scale which is dependent upon either the sulfite consumption levels or gold and silver production from the operation. For example, the royalty at the Snow Caps Mine, where the INCO process is being used to detoxify leached heaps, is based on sulfite consumption and is $0.35/lb SO_2.

DeVuyst compared the cost of the INCO and alkaline chlorination processes (*9*). Based on a tailings slurry containing 250 ppm total cyanide, 250 ppm thiocyanate, and 100 ppm thiosulfate, it is estimated that the INCO process

operation costs would be $0.95/m³ ($1.05/st) of solution treated versus $2.72/m³ ($3.00/st) for alkaline chlorination. This assumes 5.08 parts sulfite as sodium metabisulfite and 2.23 parts lime are required per part of cyanide.

DeVuyst estimated the capital costs for a system treating 3,300 st of tailings slurry daily would be $400,000 for the equipment and $600,000 for installation (*8*). For heap leach detoxification, this cost could be reduced by utilizing the barren solution pond as the reactor vessel. Operating costs for this system range between $0.08 and $1.34/st of solution treated, including royalty. The lower value is for treating clarified impounded solutions whose cyanide levels have been significantly reduced by natural degradation processes.

SUGGESTED READING

(Sulfite-Air Process)

Comba, P. G., and S. L. McGill. Rinsing of Spent Precious Metal Ores for Heap Leach Decommissioning. 1990, 13 pp.; available upon request from P. G. Comba, BuMines, Reno Research Center, Reno, NV.

Mudder, T. I. (ed.). The Copper Catalyzed Hydrogen Peroxide Process. Sec. in The Chemistry, Analysis, Toxicity, and Treatment of Cyanidation Wastewaters. Pres. at Soc. Min. Eng. AIME Short Course, Las Vegas, NV, Feb. 26, 1989, pp. 6-87 - 6-97; available upon request from SME Meetings Dep., Littleton, CO.

Palmer, S. A. K., M. A. Breton, T. J. Nunno, D. M. Sullivan, and N. F. Surprenant. Sulfur-Based Cyanide Treatment Technologies. Ch. in Metal/Cyanide Containing Wastes, Treatment Technologies. Noyes Data Corp., 1988, pp. 660-675.

APPENDIX D.—EARTHWORK, REVEGETATION, AND BONDING, GENERAL CONSIDERATIONS

EARTHWORK

Earthwork and revegetation are reclamation tasks which are interrelated and thus will be discussed together in this section. Each and every site to be reclaimed is unique because of climate and terrain which require consideration of site-specific earthmoving and revegetation techniques. The Soil Conservation Service, U.S. Forest Service (USFS), Bureau of Land Management (BLM), Office of Surface Mining (OSM), State mined-land reclamation departments, other agencies, universities, and revegetation contractors can be consulted for local conditions, best plant species, planting times, fertilizers, and revegetation costs. If the user is fortunate, information on specific earthwork and revegetation tasks may be found in the leaching operation's reclamation plan where details such as topsoil replacement, plant species to be used, and the approved post-mining land uses are provided. Unfortunately, a majority of plan of operations do not include detailed reclamation plans.

Typical earthwork items related to heap leach reclamation include recontouring heap slopes and roads, backfilling ponds, transporting and reapplying topsoil, transporting and applying clay for use as a heap capping material, ripping subsoil (conditioning), and grading topsoil. Equipment used for the earthwork tasks may include one or more dozers with ripper attachments, powered or pulled scrapers, wheel loaders, trucks, and graders.

Revegetation items related to heap leach reclamation include soil analysis, fertilization, seeding, mulching, transplanting, and irrigation. Revegetation areas at a heap leach facility would include heaps, roads, ponds, and removed structure sites.

General information on earthwork is discussed in the "Handbook for Calculation of Reclamation Bond Amounts" (*42*). The following discussion on earthwork was developed in part from that publication, as it also pertains to reclaiming heap leach process facilities.

Backfilling and grading operations serve two primary requirements: (1) to establish an acceptable post-mining topography in the mined area, and (2) to ensure a stable surface for topsoil placement and revegetation. The first requirement involves handling large amounts of material to backfill ponds, regrade heap slopes, or regrade roadcuts. The second requirement involves final grading of the site to reestablish grades along stream channels; minor road regrading; or facilities site regrading. Depending upon the operation, several different types of equipment can be used to backfill and grade the disturbed area.

Costs associated with backfilling, grading, and topsoil redistribution are estimated using the following steps: (1) develop a materials handling plan, and (2) calculate equipment productivity and costs. This section provides guidelines in developing a materials handling plan by defining and explaining important reclamation tasks. A plan includes the volume of material to be handled, haul distances and grades, and the types of equipment to be used. With a plan defined, the cost can be estimated using HEAPREC.

Standard equipment performance guidebooks and cost-estimating guidebooks can be used to estimate backfilling and grading costs or actual cost data from similar operations can be used. The costs of miscellaneous earthmoving activities, such as removal of diversion structures and roads and reconstruction of stream channels, are also included under earthmoving operations.

Material Volume Estimates

Several methods are available for determining the amount of material to be handled. In general, these methods require comparing pre-reclamation topography with post-reclamation topography. The determination of volumes can be done either by estimating the volume of geometric shapes or by developing cross sections through the areas where backfilling and grading will occur.

The total volume of material to be handled must be carefully considered. This requires the use of material swell factors. The "swell factor" is defined as the percentage increase in volume of material from bank (in place) state to loose state. When material is first cut from a bank (or its natural state), it will swell. This is called the initial swell factor. The amount of initial swell is dependent upon physical characteristics of the material involved. After the material is placed, it will tend to settle or shrink over time. The resulting final swell volume is generally one half the initial swell.

The estimator should use swell factors provided in the reclamation plan; however, care should be taken to verify the figures provided. The estimator should use the swell factors that are listed in, or that can be derived from, tables in many standard equipment productivity manuals (e.g. Caterpillar Handbook).

Another necessary factor in equipment manuals is the load factor (LF) which is defined as the relationship between the bank volume and loose volume. The LF is

equal to the loose density divided by the bank density. For example, page 887 of the Caterpillar Performance Handbook (edition 19) lists load factors for most material encountered in surface mine reclamation. The relationship between load factor and swell factor is:

$$LF = \frac{(100)}{100 + SF},$$

where LF = load factor,

and SF = swell factor.

Haul Distance Estimates

Haul distance is a primary factor affecting the cost of backfilling and grading operations and must be determined for each area where backfilling and grading will occur.

Average haul distances are identified by centroid-to-centroid distances of each material source and destination. In some instances, it may be necessary to construct additional haul roads to increase hauling efficiency.

Grade Estimates

Haul-road grades and surface conditions must be specifically considered since they are necessary for determining the equipment to be used and its productivity. Most equipment manuals require a determination of the total resistance (TR) of the haul. Total resistance is the combination of rolling resistance (RR) and resistance due to percent grade (GR) and may be expressed as:

$$TR\ (\%) = RR\ (\%) + GR\ (\%).$$

Frequently, the RR component is expressed as an equivalent percent grade. Tables showing the RR as an equivalent percent grade can be found in most equipment manuals for various types of road and work-area surface conditions.

Equipment Selection

The selection and matching of equipment is critical in calculating an accurate and justifiable performance bond. Factors to consider include equipment horsepower, capacity, cycle time, site conditions such as space limitations, and material characteristics that affect equipment performance. Familiarity with equipment can be gained by the review of equipment production guides available from the manufacturer. Compare two or more combinations of equipment to determine which is the most efficient for a given reclamation task.

In the event of a bond forfeiture, the mine operator and his equipment will not be available to complete the reclamation work. The estimator should check with several regional earthmoving contractors to determine what, if any, large specialized pieces of equipment may be available for the reclamation job. If possible, obtain performance and cost data on the specialized equipment and compare the overall cost of completing the earthmoving task with the specialized vs standard equipment.

Bulldozers

The bulldozer is a very effective tool for earthmoving. It is used for moving and regrading subsoils and topsoils for heaps, roads, ponds, and facilities areas. Haul distances over a few hundred feet are not advised as costs exceed other equipment types. Specifically, bulldozers should be considered for up to 300 ft hauls and may be considered at up to 500 ft. Bulldozers equipped with ripper(s) condition the subsoil prior to topsoil application. Grading areas prior to topsoil application or seeding is also accomplished with a bulldozer.

Ripping and earthmoving rates depend on bulldozer horsepower, haul gradient, operator skill, and job efficiency. Material should be easy to move, and a factor of one is assumed. Select a bulldozer based on a horsepower rating of between 300 and 450 hp although bulldozers for reclamation range from 200 to 700 hp. Universal (reclamation) blades are used for backfilling and rough grading, and straight blades are used for final grading. High costs will be incurred and cautioned when estimating regrading slopes on heaps to shallow angles.

Front-End Loaders

Front-end loaders are effective because they self-load, haul, and dump. No additional equipment is required. They can be used to relocate topsoil from stockpiles to reclaiming area. Front-end loaders are efficient at distances from approximately 300 to 800 ft. Front-end loaders are also used in conjunction with trucks for loading purposes only. The bucket size should be compatible with truck capacity. Bucket size capacities range from 3 to 7 yd^3 for reclamation work.

Rear-Dump Trucks

Trucks are the best method for hauling long distances. However, since other equipment is required for loading, the total transportation expense over short distances may be higher than for front-end loaders or scrapers. A minimum distance of approximately 1,000 ft is suitable for truck haulage. Tasks requiring off-highway truck haulage

may be to haul subsoil or topsoil material from remote sources (operating radius of 3 miles). Trucks require fairly good road surfaces and careful matching with loading equipment to achieve acceptable loading efficiency. Most reclamation tasks require off-highway truck capacities of 35 to 63 st (26 to 48 yd^3).

Scrapers

Scrapers are noted for their high productivity. Scrapers are capable of much higher speeds and greater capacity than front-end loaders with haulage characteristics similar to trucks. Scrapers can be self-loading but may require assistance from a bulldozer or another scraper when loading. The worksheet assumes the use of push-pull scrapers. Push-pull scrapers used in pairs eliminate the need for a push tractor. Scrapers are ideal for unloading because the scraper dumping mechanism facilitates spreading of the material, decreasing grading requirements. Distances from approximately 500 ft to 5,000 ft are suitable for scraper haulage. Scrapers with capacities of 20 to 35 yd^3 are typical for reclamation activities.

Backhoe-Excavator

The backhoe is an ideal tool for backfilling and regrading roads on steep slopes. The backhoe is also anticipated to be used to aid in loading pond sludge into trucks to be hauled to a dump site or for mixing cement into pond sludge for on-site burial. Backhoe size required is dependent on road width and slope angle to attain proper reach of excavator arm. The bucket size should be compatible with truck capacity for loading sludge. Bucket size ranges from 1.5 to 5 yd^3.

Motor Graders

In some instances, a motor grader may be used in place of a bulldozer for final grading, light leveling work, and diversion ditch construction. Motor graders for reclamation work range from 125 to 275 hp.

Subsoil Earthmoving

Subsoil earthmoving will be required for recontouring heaps, backfilling ponds, and recontouring roadcuts. Slope stability for heaps is achieved by reducing slopes from their natural angle of repose (27° to 30°) to a reclaimed slope ranging from 16° to 22°. Site-specific conditions, such as seismicity, amount and frequency of precipitation, material type, and other factors that affect stope stability must be considered when making a determination of a stable stope angle. A stable stope can also be achieved with terracing, which reduces the overall slope angle to a site-specific stable angle. Backfilling ponds and roads is accomplished by utilizing material side cast during construction, utilizing imported material such as detoxified heap material or the mine's waste rock, by the reduction of the cut slope angles, or by a combination of these methods. A dozer can be used for all recontouring operations although backhoes are commonly used in road reclamation, especially in steeply sloping terrain, greater than 40°. Water from precipitation events should not be allowed to be concentrated on reclaimed terraces, slopes, or heap tops. Where possible, heap tops should be graded to angle away from heap side slopes. Where this is not possible, heap tops should be convex to disperse water. Heap side slopes should be regraded so that water is not concentrated as it migrates downslope. Concave faces which are wide at the top and narrow at the toe will concentrate water and cause uncontrollable erosion in areas with sufficient precipitation.

Final grading of the subsoil prepares the disturbed area for receiving topsoil. Final grading ensures large rocks will be buried to allow proper drainage, and to ensure the reclaimed topography fits into the surrounding undisturbed contour by smoothing out hills and gullies left by backfilling operations. The final graded surface should be left slightly rough to assist in bonding backfill to the topsoil. Equipment commonly used for grading subsoil are scrapers, dozers, and motor graders.

Subsoil Conditioning

The rough-graded surface of the subsoil material should be loosened by ripping to properly accept topsoil. This will reduce potential slippage planes between the topsoil and subsoil and facilitate root penetration. The USFS recommends ripping subsoil on 18-in centers and to a depth of 18 to 24 in (*41*). Ripping should be done when subsoil is dry to permit shattering beneath the surface. Subsoils toxic to plant life require greater thicknesses of overlying topsoils. An option is to use alternative subsoil and geologic materials as the base to reduce the required topsoil thickness. Toxic subsoils can also be isolated by the use of construction techniques which impede root migration. These techniques include french drains and other water draining structures.

Soil Analysis

General guidelines for assessing soil suitability for use as topsoil are provided in table D-1. Soils classified as poor should be avoided and soils in the unsuitable category should be buried 12 to 48 in. depending on the exact nature of the material.

Table D-1.—Soil suitability for reclamation use

Soil property	Soil quality			
	Good	Fair	Poor	Not suitable
Texture	Sandy loam Loam Silt loam	Sandy clay loam Silty clay loam Clay loam	Sandy clay Loamy sand Silty clay	Clay >60%
Rock and gravel	<10%	10-20%	20-40%	>40%
pH	6-8	5-6 or 8-8.5	4.5 or 8.5-9	<4.5 or >9
Sodium absorption ratio (SAR)	<4	4-8	8-16	>16
Electrical conductivity (mmhos/cm)	<3	3-7	7-15	>15

Source: (*41*)

Topsoil Redistribution

Topsoil redistribution includes transporting previously stockpiled soils to the revegetation site and grading the soil evenly to the required thickness. If subsoils are nontoxic to plants or have no other detrimental properties, the USFS recommends that 12 in of topsoil be applied. Less topsoil may be required if subsoils are fine-textured and have desirable plant growth properties. Coarse-textured or rocky subsoils may require up to 24 in of topsoil. To reduce topsoil rutting and compaction when applying, avoid wet weather conditions. Harrowing is recommended for topsoil on level areas and on slopes less than 33% grade. Harrowing breaks up surface compaction caused by topsoiling operations.

Equipment used in topsoil hauling and redistribution is dependent on the hauling distance and the amount of topsoil to be reapplied. Equipment type, size, and availability must be carefully considered. In HEAPREC, a motor grader can be selected to final grade topsoil on near-level areas (grades less than 25%); on steeper slopes, grading must be accomplished using a dozer. A dozer can also be used to stabilize the topsoil on slopes. This involves operating the dozer up and down the slope, allowing the dozer treads to create grooves perpendicular to slope direction. This procedure helps control erosion during seed germination. If available, a slope disc can be used to harrow the topsoil on slopes. Harrowing costs in general are not included in HEAPREC. On excessively long slopes, terracing may be required to decrease erosion potential.

SUGGESTED READING

(Earthwork)

Caterpillar Tractor Company. Caterpillar Performance Handbook. Peoria, IL, 19th ed., 1988, 928 pp.

Tourbier, J. T., and R. Westmacott. A Handbook for Small Surface Coal Mine Operators. Univ. Delaware, Newark, DE, (U.S. Office of Surface Mining (Dep. Interior) grant No. 14-34-0001-8900), 1980, 130 pp.

U.S. Forest Service (Dep. Agriculture). Cost Estimating Guide for Road Construction. Region 4, Div. Eng., June 1990, 53 pp.,; available upon request from the U.S. Forest Service, Intermountain Region, Ogden, UT.

U.S. Forest Service (Dep. Agriculture). R-4 Reclamation Field Guide. Region 4, Miner. Management, Ogden, UT, 1990, 81 pp.

REVEGETATION

Fertilization

The soil should be tested for nutrient levels before adding fertilizers, then fertilize as needed. Disturbed lands are usually deficient in nitrogen and phosphorus and often require from 50 to 500 lb/acre. Other macro nutrients that plants need in large quantities are potassium, calcium, magnesium, and sulfur. Micro nutrients include boron, copper, manganese, zinc, iron, molybdenum, and chlorine. Harrow fertilizer into the soil to increase effectiveness.

Seed Selection and Handling

A suitable mix of plant species is dependent on the site environment and seed availability. Selection of appropriate grasses and forbs is dependent on original species occurrence, post-operation site conditions and land use, establishment potential, growth characteristics, soil adaption and stabilization quantities, suitability for wildlife, and commercial availability (*4*). Seeds for revegetation must be from a source that has a similar elevation and climate. For example, seeds grown in high mountain climates will not succeed in a high desert climate. Lists and descriptions of grasses, forage legumes, shrubs, and trees commonly used in soil conservation may be found in the following publications. Complete bibliographies for these publications are presented in the Reference section.

(1) R-4 Reclamation Field Guide, U.S. Forest Service (Dep. Agriculture). Lists plant species suitable for adverse conditions including moderately acid soils, moderately saline soils, and plants that are drought-resistant.

(2) R-4 Plant Species List for Reclamation of Disturbed Sites, U.S. Forest Service (Dep. Agriculture). Lists species for salt desert shrub areas, sagebrush-foothill areas, sagebrush-pinion juniper-mountainbrush areas, and upper mountain elevations.

(3) A Manual for Training Reclamation Inspectors in the Fundamentals of Soils and Revegetation, U.S. Forest Service (Dep. Agriculture). Lists and describes plant species for revegetating coal surface-mines lands in the Western Region.

(4) Design of Non-Impounding Mines Waste Dumps, Soc. Min. Eng. AIME, 1985. Lists preferred vegetation on seven environmentally different minesites in the Intermountain Rocky Mountain Region.

(5) Reclamation of Surface-Mined Lands, CRC Press, Inc. Lists adapted grasses and herbaceous legumes of the United States that hold potential value for land restoration programs.

(6) Reclamation of Mined Lands in the Western Coal Region, U.S. Geol. Surv. Circ. 872. Lists plant species used in Western Coal Region reclamation.

(7) Small Surface Coal Mine Operators Handbook, U.S. Office of Surface Mining (Dep. Interior). Lists and describes grasses, forage legumes, shrubs, and trees used in soil conservation in the eastern United States.

(8) A Handbook for Meeting Fish and Wildlife Information Needs to Surface Mine Coal, U.S. Office of Surface Mining (Dep. Interior), 1981. Lists plant species recommended by State or Federal agencies for wildlife habitat development.

In severe environments such as alpine and desert, or where soils are too acidic or basic, the number of adapted species suitable for planting are less than those available in more moderate climates or more neutral soils. Legumes have a low tolerance for soils with a low pH (*39*, p. 122). The most tolerant legumes include Birdsfood Trefoil, Sericea Lespedeza, and annual Lespedeza (*39*, p. 122). Grasses that perform well in acidic soils include Weeping Lovegrass, Blackwell Stitch grass, and Kentucky 31 Tall Fescue (*39*, p. 122).

Seed Acquisition

Seed of adapted plant species may either be collected from plants in the vicinity of the reclamation site or purchased from a seed dealer or distributor. Seed collection by hand or mechanized equipment may be expensive. Care must be taken to observe plants for seed maturity as collection must be performed at the proper time. Seeds mature at varied rates and times so several collection trips are required. Seed purchased from a reputable seed collector and dealer is usually less expensive and less laborious. Seed germination percent, collection location, species name, pure live seed ([PLS] seed that will germinate), and percent weed or other contaminates should be identified.

Seeding

The two basic methods of seeding are drilling and broadcast seeding. Generally, the components of a drill seeding device include a storage container-agitator, seed metering, transfer tubes, a soil opener, and soil covering. Using a drill or cultipacker-type seeder assures seeds are planted at the proper depth and in effect covered to provide a hydraulic contact with the soil. Drill seeding costs are not included in the cost estimation worksheet. Broadcast seeding includes container storage-agitation and metering. Seeds can be broadcast using manually operated cyclone-type spreaders or a mechanical seed blower.

Broadcast seeding should be done immediately following topsoil preparation so that soil will settle around the seed, providing a seed-soil contact. Use a light chain, log drag, or roller, where possible, to cover the seed. Schedule planting just prior to the longest precipitation period or when moisture is most favorable for seedling establishment. A very general rule is to plant at a depth 2.5 times the diameter of the seed. It is much faster and cheaper to broadcast seeds rather than to open drill rows and drop in seeds. Certain seeds have to be broadcast on the soil surface to have an opportunity for germination and establishment but the majority of seeds benefit from soil coverage.

Hydroseeding is a form of broadcast seeding. The seed is broadcast with a high-pressure stream of water from a truck-mounted tank. Fertilizer and mulch can also be mixed with water and seed and applied at the same time. Hydroseeders can reach steep slopes and highwalls that cannot be reached by other types of seeders. Disadvantages are that a water source is required near the site, time is required to fill the tank, and when mulch is added to the mix, only a relatively small area can be seeded with each tankful.

Seeding rates vary depending on site conditions, seed type, and seed mixture. Seed rates and seedling planting rates are discussed in mine reclamation plans. As an example from several plans, the range of seed used by weight was from 6.2 lb PLS/acre to 17.45 lb PLS/acre. The range of application rates in seed count was from 52 PLS/ft^2 to 145 PLS/ft^2. Higher seed rates are required when using broadcasting methods and on less desirable soils. Williamson recommends seeding rates as shown in table D-2 (*45*).

Table D-2.—Recommended seeding rates

(Based on 1,000 seeds per gram)

Method	Application rate pound PLS per acre	
	Nontoxic site	Exposed toxic site
Broadcast seed:[1]		
With mulch	45	89
Without mulch ..	71	178
Drilled seed	22	45

[1]Includes hydroseeding.

Source: (*45*, p. 79).

Mulching

Mulches are used to protect and stabilize soils until permanent plant cover is established. A good mulch cover prevents erosion and protects seeded areas from heat, cold, and drought. Commonly used mulches include straw, hay, woodchips, jute, excelsior, synthetic biodegradable fiber, animal manure, or sewage sludge. Mulch should be applied to a roughened surface. Use asphalt or other suitable tackifiers to stabilize mulch or crimp mulch into the surface using a dozer. Common hay and straw mulches are typically applied at the rate of 2,000 to 4,000 lb/acre. Small areas can be hand applied, and larger areas require a power blower or mulcher. Fiber mulches can be applied effectively in a slurry of water, seed, and fertilizer using a hydromulcher. The application rate should be at least 1,500 lb/acre. On slopes greater than 3:1, it may be desirable to use commercially available mulches such as jute or excelsior. Hydromulches are often the best solution for moderately steep slopes.

Trees and Shrubs

Trees and shrubs are not as important as herbaceous cover for controlling erosion (*39*, p. 116). Considerations must be taken for end use, consistency with local vegetation, landscape characteristics, and must be compatible with land-use plans developed by State and/or Federal agencies. Transplanting is recommended on small or critical revegetation sites but it can be labor intensive and expensive. Source plant materials may be found commercially or may be collected on site. The availability of water is one of the most important factors affecting the survival of young tree seedlings in competition with herbaceous cover (*39*, p. 116). Pines generally adapt better to dry conditions, and hardwoods are more tolerant in excessively wet, poorly drained areas (*39*, p. 117).

Planting 800 to 1,000 trees per acre usually is recommended for conservation purposes and for development of a productive forest (*44*). A 6- by 7-ft spacing is equivalent to 1,035 plants per acre. Tree farms usually plant at 5- to 6-ft spacings (*44*). Competition by herbaceous vegetation can be reduced by scalping off vegetation using a plow or similar implement, application of herbicides, or mulching the ground cover around plantings (*44*).

SUGGESTED READING

(Revegetation)

Sendlein, L. V. A., H. Yazicigil, and C. L. Carlson (eds.). Surface Mining Environmental Monitoring and Reclamation Handbook. Elsevier Sci. Publ., New York-Amsterdam-Oxford, 1983, 750 pp.

Tourbier, J. T., and R. Westmacott. A Handbook for Small Surface Coal Mine Operators. Univ. Delaware, Newark, DE, (U.S. Office of Surface Min. [Dep. Interior] grant No. 14-34-0001-8900), 1980, 130 pp.

U.S. Forest Service (Dep. Agriculture). R-4 Reclamation Field Guide. Region 4, Miner. Management, Ogden, UT, 1990, 81 pp.

Vogel, W. G. A Manual for Training Reclamation Inspectors in the Fundamentals of Soils and Revegetation. Soil and Water Conserv. Soc., 1987, 178 pp.

U.S. Bureau of Land Management (Dep. Interior). Reclamation Handbook H-3042-1. 1991, 172 pp.

STRUCTURE REMOVAL

Removal of structures includes buildings, storage systems, and their foundations. Usually all structures would be removed from the reclamation site with exceptions only if the mine's closure plan requires the structure's use in post-mining. The type of buildings to be removed are very important. Office structures commonly consist of mobile sections on temporary foundations. Shop and plant buildings are often steel-frame structures with metal siding. In both cases, the salvage value of the structure may exceed the removal cost. If structure removal includes demolition and removal of debris to a disposal site, the most commonly used guidebook to estimate these costs is the Building Construction Cost Data (*21*). For heap leach operations, structure demolition, removal, on-site burial is a small percentage of the total cost to reclaim the site.

To properly estimate structure demolition and removal costs, data describing the physical characteristics of all structures present must be collected. If demolition is required, consider building material, volume or size of the structure, demolition cost per unit volume of the structure, type of foundation, access, distance to disposal site, haul costs, and disposal fees. HEAPREC facilitates inclusion of unit demolition costs, both on-site and off-site.

POND LINER REMOVAL AND DISPOSAL

Heap leach processes include a pregnant solution pond and a barren solution pond. Other ponds that may exist

include emergency overflow ponds or additional pregnant or barren ponds. Since ponds are constructed using plastic liners, the reclamation practice may include folding and burying the liner in place or it may be acceptable to perforate the liner and bury it in place. Alternatively, the liner could be removed from the area by excavation and disposed in a landfill.

Sediment is formed in ponds during the heap leach operation and can contain metals and compounds which may be considered hazardous waste. The EPA requires a toxicity characteristic leaching test (TCLP) for hazardous waste under Subtitle C regulations. Although mining wastes are classified under subtitle D and do not require this test, the State in which the mine is located may require such testing. The estimator should check State and local regulations on testing and transportation of waste. Normal pond maintenance programs include periodic removal of pond sediments. Some properties have permitted areas, such as lined tailings ponds, where liner and sediments can be disposed. Relocating sediments to the heap leach pad is also a common acceptable practice. For estimation purposes, assume a sludge accumulation of 1.5 ft thick on the pond bottom.

If the sludge meets the requirements to be buried on-site, cement is usually added at 20% by weight, then mixed to solidify the material. If plans are made to transport the sediment to an off-site Class A landfill, additional out-of-State fees may be required for the sediment and/or the liner. A typical out-of-State fee is $140/st; in-State fees would be less. Haulage rates to landfill sites can range from $0.10 to $0.50/st-mi depending on haulage distance.

CAPPING HEAPS

If a heap can not be successfully detoxified in a reasonable amount of time, some regulations may require the heap to be capped to lessen the possibility of discharge from infiltrating precipitation. State of Montana regulations stipulate if heap detoxification methods fail, then the heap must be capped to prevent penetration and percolation of waters through the heap. Montana design standards include the application of two 6-in lifts of compacted clay with a rated permeability less than 10^{-6} cm/s, an overlying 6-in lift of minus 1 in angular gravel, and a topsoil of substantial thickness to promote seed growth. The 6-in lift of angular material layer acts as a drainage zone for the topsoil to prevent a hydraulic head buildup on the clay cap. Although regulations may vary State-by-State, Montana's heap capping guidelines could be considered a nonregulatory rule-of-thumb for capping design. Capping costs can be calculated using the cost estimation worksheet. A specific calculation range is used to estimate costs to crush and screen gravel and to haul and apply the clay and gravel layers.

Rinse methods may fail if heap permeability has decreased significantly prior to or during the rinse or if blind offs within the heap have occurred, thus preventing a complete rinse. Blind offs are interior portions of the heap in which permeating leach fluids bypass. A possible alternative to heap capping is to excavate the heap to locate blind offs or increase the heap permeability, then detoxify material as required on the existing pad or a newly constructed pad.

INDIRECT RECLAMATION COSTS

Indirect costs are those fees and charges that are over and above the direct reclamation costs and are determined as a percentage of direct costs. Indirect costs include mobilization and demobilization, contingencies, engineering redesign costs, profit and overhead, and reclamation management fees. Indirect cost percentages were derived from the "Handbook for Calculation of Reclamation Bond Amounts" (*42*). The following discussion on indirect costs is taken in part from that publication.

Mobilization and Demobilization

This category of indirect costs is an allowance for the cost of moving personnel, equipment, supplies, and incidentals to and from the reclamation site. Also included are establishment of field offices, buildings, and other facilities needed to proceed with the project. Costs will vary based on the type and number of equipment to be hauled and the distance to the site. The 3% used in cell B45 should be considered a starting point for the estimate; compare this cost with an actual estimate. This allowance normally ranges between 1% and 5% of the total direct costs. Bids obtained by USFS Region 4 reflect mobilization costs of 6% to 10% of the total project cost (*40*).

Contingencies

A contingency cost should be included in the bond amount to provide for project uncertainties, incidentals (renting portable toilets, site security, etc.), and unexpected natural events. The contingency percentage is based on the amount of direct costs and ranges between 2% and 10%. The range is based on experience attained by the Office of Surface Mining.

Engineering Redesign Fee

The reclamation plan submitted by the operator as part of the operating plan assumes the operation will continue for the full permit term. However, the reclamation plan may not adequately reflect site conditions at the time of forfeiture. Therefore, a new reclamation design may need

to be developed or the existing one may need modification. Engineering redesign may include:

(1) preparation of maps and plans to show the extent of required reclamation;

(2) surveying of topsoil and overburden stockpiles to determine amount of material available;

(3) analysis of topsoil and overburden piles to determine whether special handling or treatment is necessary;

(4) evaluation of structures to determine requirements for demolition and removal;

(5) evaluation of impoundments to determine if treatment, clean out, or other improvements are necessary;

(6) assessment of reclaimed areas to determine whether completed reclamation was satisfactory.

Engineering redesign cost is a function of the total direct costs. The percentage of direct costs ranges between 2% and 10%. In some cases, the estimator may be justified in applying a different percentage to obtain the engineering redesign cost.

Profit and Overhead

It is assumed that a third party will do the actual reclamation work. The third party's profit and overhead must be included in the cost estimate. Profit and overhead are not included in any previously mentioned indirect cost category. These costs are a function of direct costs and range between 3% and 14%.

Reclamation Management Fees

The reclamation management fee (cell C49) should account for the regulatory agency's cost to inspect and supervise the reclamation. Management duties may include recommending change orders, verifying completed work, verifying compliance with project specifications, and other reclamation management oversight activities. This fee can be highly variable; in fact, some agencies may not even require accounting for it. If agency policy requires a different percentage, change the template as needed. The fee is a function of direct costs and typically ranges between 2% and 7%.

RECLAMATION COST CALCULATION

HEAPREC incorporates calculations for earthwork and revegetation. Raw costs, such as labor, equipment, and seed, must be derived by the worksheet user. Earthwork and revegetation costs can also be estimated using the Cost Estimating Guide for Road Construction (*40*). Pertinent cost data from this Guide are referenced in table D-3. Some of these rule-of-thumb data were incorporated into HEAPREC. Mine reclamation costs are site-specific and highly variable. Generic costs, as well as the cost estimation worksheet, must be used with great care and discretion. Specific costs on all aspects of earthwork and revegetation can be acquired from Building Construction Cost Data (*21*) and from Dataquest or similar manuals.

Table D-3.—Earthwork and revegetation unit costs

Activity	Cost, $	Cost, $/acre
Earthwork:		
Subsoil recontouring	0.95/yd^3	NAp
Subsoil ripping	NAp	[1]283
Topsoil stockpile excavation	0.95/yd^3	[2]1,520
Hauling	0.50/st-mi	NAp
Spreading	1.10-1.35/yd^3	[2]1,770- 2,178
Topsoil scarifying	NAp	[1]57
Final grading-leveling	NAp	[1]85
Terracing slopes	[2]1.00/lin ft	NAp
Revegetation:		
Dry seed	NAp	100
Dry mulch, hay or straw[3]	NAp	400- 500
Fertilize	NAp	200
Hydroseed[4]	NAp	600- 700
Mulch, emulsified asphalt[5]	NAp	800- 1,000
Erosion control jute mesh	1.00/yd^2	4,840
Transplanting:[6]		
Trees, bare root	10-20 ea	4,350- 8,700
Trees, balled and burlapped	30-80 ea	13,000-34,800
Shrubs	5-10 ea	2,175- 4,350

NAp Not applicable.

[1]Richins, 1986. Costs indexed to June 1990.

[2]Based on 12-in lift of topsoil uncompacted.

[3]Includes seeding at 35 lb/acre, fertilizer at 200 lb/acre, and straw or hay at 4,000 lb/acre. Cost is for greater than 20 acres.

[4]Same seed and fertilizer mixture as dry mulching and includes wood cellulose fiber at 2,000 lb/acre. Cost is for greater than 20 acres.

[5]Same seed and fertilizer mixture as dry mulching and includes straw or hay at 4,000 lb/acre and asphalt at 400 gal/acre. Cost is for greater than 20 acres.

[6]Cost per acre is based on plant spacing of 10 by 10 ft.

Source: (*40*), unless otherwise noted. Costs are based on labor rates in the Intermountain Region (USFS Region 1 and 4). Labor constitutes 35% to 50% of costs from this source.

SUGGESTED READING

(Reclamation Cost Calculation)

Dataquest Inc. Cost Reference Guide for Construction Equipment. The Dun & Bradstreet Corp., San Jose, CA, 1990, 23 sections.

Mahoney, W. D. (ed.). Building Construction Cost Data, Western Edition. R. S. Means Co., Inc., 1990, 502 pp.

Stebbins, S. A. Cost Estimating Handbook for Small Placer Mines. BuMines IC 9170, 1987, 94 pp.

Western Mine Engineering. Mining Cost Service. Spokane, WA, 1990.

U.S. Forest Service (Dep. Agriculture). Cost Estimating Guide for Road Construction. Region 4, Div. Eng., June 1990, 53 pp.; available upon request from U.S. Forest Service, Intermountain Region, Ogden, UT.

U.S. Bureau of Land Management (Dep. Interior). Reclamation Handbook H-3042-1. 1991, 172 pp.

APPENDIX E.—HEAPREC EQUATIONS

Pertinent equipment productivity and cost equations used to develop the HEAPREC are included in this appendix. The equations are organized by section as presented in the HEAPREC User's Manual as follows: SUBSOIL EARTHWORK, OTHER DOZER APPLICATIONS, TOPSOIL APPLICATION, TOPSOIL GRADING, REVEGETATION, STRUCTURE DEMOLIITION, LINER DISPOSAL, CAPPING HEAP, and DETOXIFICATION METHODS.

SUBSOIL EARTHWORK

**** Scraper - Subsoil Earthwork (A121..F140) ****

Description: Estimate costs to haul and reapply subsoil using a scraper.

Input data: Haul distance, amount of material to move.

Data range: Scraper capacity, hourly equipment operation, hourly labor cost.

Given data: None.

Production equation:

$$P = \frac{600 \times C}{H/100 + 30},$$

where P = production (yd^3/h),

C = scraper capacity (yd^3),

and H = haul distance one way (ft).

The equation gives a rough estimate of production by assuming a scraper speed of 22.7 mi/h requiring 15 hp/yd^3 scraper capacity and a fixed time for loading, accelerating, turning, and dumping of 3 min per cycle.

Total scraper time equation:

$$T = \frac{M}{P} \times \frac{1}{80\%},$$

where T = Total scraper time (h),

M = amount of material to moved (yd^3),

and P = production (yd^3/h).

Total scraper time is adjusted using an 80% operator efficiency factor.

Total cost equation:

$$TC = (HCL + HCE) \times T,$$

where TC = total cost ($),

HCL = hourly labor cost ($/h),

HCE = hourly equipment cost ($/h),

and T = total scraper time (h).

**** Wheel Loader - Subsoil Earthwork (A141..F160) ****

Description: Estimate costs to haul and reapply subsoil using a wheel loader.

Input data: Haul distance, amount of material to move.

Data range: Wheel loader capacity, hourly equipment operation, hourly labor cost.

Given data: Loader operating speed, load-dump-maneuver time.

Cycle time equation:

$$CT = \frac{H \times 2}{S \times 88} + LDM,$$

where CT = cycle time (min),

H = haul distance one way (ft),

S = average loader operating speed (mi/h),

and LDM = load-dump-maneuver time (min).

Number of trips equation:

$$NT = \frac{M}{C},$$

where NT = number of trips,

M = amount of material to move (yd^3),

and C = wheel loader capacity (yd^3).

Time equation:

$$T = NT \times \frac{CT}{60} \times \frac{1}{80\%},$$

where T = total wheel loader time (h),

NT = number of trips,

and CT = cycle time (min).

Total scraper time is adjusted using an 80% operator efficiency factor.

Cost equation: See Scraper - Subsoil Earthwork cost equation (A121..F160).

***** Wheel Loader-Truck - Subsoil Earthwork (A161..F200) *****

Description: Estimate costs to haul and reapply subsoil using a wheel loader to load topsoil and trucks to haul to the reapplication site.

Input data: Haul distance, amount of material to move.

Data range: Wheel loader and truck capacity, hourly equipment operation, hourly labor cost.

Given data: Truck and wheel loader operating speed, wheel loader load-dump-maneuver time, truck maneuver and dump time.

Buckets per truckload equation:

$$BT = \frac{TC}{LC},$$

where BT = wheel loader buckets per truckload,

TC = truck capacity (yd^3),

LC = wheel loader capacity (yd^3).

The equation accounts for a partial final bucket required to fill truck. The loader time per truck load is calculated by multiplying the number of buckets required per truck by the wheel loader cycle time:

Loader time per truck equation:

$$LT = BT \times LCT,$$

where LT = loader time per truck (min),

BT = wheel loader buckets per truckload,

and LCT = wheel loader load-maneuver-dump time (min).

Truck loads required equation:

$$TL = \frac{M}{TC},$$

where TL = truck loads required,

M = amount of material to move (yd^3),

and TC = truck capacity (yd^3).

Truck cycle time equation: The time for a truck to be loaded, haul, and return.

$$TCT = \frac{H \times 2}{TS \times 88} + TMD + LT,$$

where TCT = truck cycle time (min),

H = haul distance one way (ft),

TS = truck speed (mi/h),

TMD = truck maneuver-dump time (min),

and LT = loader time per truck (min).

Optimum number of trucks equation:

$$ONT = \frac{TCT}{LT},$$

where ONT = optimum number of trucks,

TCT = truck cycle time (min),

and LT = loader time per truck (min).

The quotient is rounded down to an integer based on the assumption that the wheel loader will have some idle time rather than the trucks.

Total time per truck equation:

$$TPT = \frac{TL \times TCT/60}{ONT} \times \frac{1}{80\%},$$

where TPT = time per truck (h),

TL = truck loads required,

TCT = truck cycle time (min),

ONT = optimum number of trucks.

Time per truck is adjusted using an 80% operator efficiency factor. Total loader time equals total time per truck.

Cost equation:

$$C = ([THEC + THLC] \times ONT \times TPT) + ([LHEC + LHLC] \times TLT),$$

where C = total cost ($),

THEC = truck hourly equipment cost ($/h),

THLC = truck hourly labor cost ($/h),

ONT = optimum number of trucks,

TPT = time per truck (h).

LHEC = wheel loader hourly equipment cost ($/h),

LHLC = wheel loader hourly labor cost ($/h),

and TLT = total loader time (h).

****** Dozer - Subsoil Earthwork (A201..F220) ******

Description: Estimate costs to move subsoil using a dozer.

Input data: Haul distance, amount of material to move, percent grade in haul direction.

Data range: Dozer horsepower, hourly equipment operation, hourly labor cost.

Given data: None.

Production equation:

$$P = \begin{cases} (-0.022 \times [G] + 1) & \text{if } 30\% \geq (G) \geq -30\%, \\ \dfrac{HP \times 300}{D + 50} \times F1 \times F2 \times (0.35) & \text{if } [G] > 30\%, \\ & \text{or} \\ (1.65) & \text{if } [G] < -30\%, \end{cases}$$

where P = production (yd^3/h),

HP = dozer horsepower (hp),

D = haul distance one way (ft).

G = grade (%).

F1 = operator skill factor.

and F2 = operation efficiency and other factors as necessary.

This equation is adjusted for percent grade using equations derived from a graph relating dozer efficiency to grade (Caterpillar Handbook).

Dozer time equation:

$$T = \frac{M}{P},$$

where T = dozer time (h),

M = amount of material to move (yd^3),

and P = production (yd^3/h).

Cost equation: See Scraper - Subsoil Earthwork cost equation (A121..F140).

****** Backhoe-Excavator - Subsoil Earthwork (A221..F240) ******

Description: Estimate costs to excavate subsoil using a backhoe or excavator.

Input data: Amount of material to move, bucket percent payload.

Data range: Bucket capacity, hourly equipment operation, hourly labor cost.

Given data: Backhoe-excavator cycle time.

Production equation:

$$P = \frac{BC \times PP}{BCT/3600},$$

where P = production (yd^3/h),

BC = bucket capacity (yd^3),

PP = percent payload (%),

and BCT = backhoe-excavator cycle time (s).

Backhoe-excavator time equation: See Dozer - Subsoil Earthwork time equation (A201..F220).

Cost equation: See Scraper - Subsoil Earthwork cost equation (A121..F140).

OTHER DOZER APPLICATIONS

**** Dozer - Recontouring Heap (A241..F260) ****

Description: Estimate costs to recontour the slopes on heaps to a lower angle.

Input data: Heap crest distance, heap slope angle, final slope angle, heap height.

Data range: Dozer horsepower, hourly equipment operation, hourly labor cost.

Given data: None.

This area is multiplied by heap crest distance to be recontoured (distance = x) and the product is a volume in cubic yards to be moved. This volume is dependent on heap height, heap slope before and after grading, and heap crest distance:

Cross-sectional heap slope area to move equation:

$$A = \frac{H^2}{8} \times (1/\text{TAN}\,[GA] - 1/\text{TAN}\,[OA]),$$

where A = heap slope area to move (ft^2),

H = heap height (ft),

GA = graded heap slope angle (degree),

and OA = original heap slope angle (degree).

The overlapping cross sections representing heap slope before and after recontouring result in two triangles equivalent in area. From this overlap, an area of one triangle is determined which constitutes a d(x) volume of material to be moved.

Material to move equation:

$$M = A \times \frac{HCD}{27},$$

where M = amount of material to move (yd^3),

A = heap slope area to move (ft^2),

and HCD = heap crest distance (ft).

The HCD is the third dimension required to calculate volume of material to move.

Haul distance equation:

$$HD = \frac{2 \times H}{3 \times \text{SIN}\,([GA + OA]/2)},$$

where HD = haul distance (ft),

H = heap height (ft),

GA = graded heap slope angle (degree),

OA = original heap slope angle (degree).

The haul distance is the calculated distance between centroids of the two triangles represented in the overlapping cross sections as described above.

Production equation: See Dozer - Subsoil Earthwork production equation (A201..F220).

Dozer time equation: See Dozer - Subsoil Earthwork time equation (A201..F220).

Cost equation: See Scraper - Subsoil Earthwork cost equation (A121..F140).

**** Dozer - Grading Level Areas, Subsoil (A261..F280) ****

Description: Estimate costs to grade subsoil on level areas using a dozer.

Input data: Area to be graded.

Data range: Dozer blade width, hourly equipment operation, hourly labor cost.

Given data: Average dozer speed, average pass length, dozer maneuver time.

Dozer travel distance equation:

$$TD = \frac{A \times 43560}{GW}.$$

where TD = dozer travel distance (ft),

A = area to be graded (acre),

and GW = dozer grading width (ft).

$$T = \left(\frac{TD}{5 \times 88} + \frac{NP_2 \cdot MT}{i}\right) \frac{1}{60} \times \frac{1}{80\%}$$

99 ft/sec → mph

Number of passes equation:

$$NP = \frac{TD}{PL},$$

where NP = number of passes,

TD = dozer travel distance (ft),

and PL = dozer pass length (ft).

Dozer time equation:

$$T = \left[\frac{TD}{S \times 88} + \frac{NP \times MT}{60}\right] \times \frac{1}{(F1 \times F2)},$$

where T = dozer time (h),

TD = dozer travel distance (ft),

S = average dozer speed (mi/h),

NP = number of passes,

MT = dozer maneuver time (s), minutes

F1 = operator factor,

and F2 = job efficiency factor.

Cost equation: See Scraper - Subsoil Earthwork cost equation (A121..F140).

****** Dozer - Grading Slopes, Subsoil (A281..F300) ******

Description: Estimate costs to grade subsoil on slopes using a dozer.

Input data: Slope distance, slope width, grade.

Data range: Dozer blade width, hourly equipment operation, hourly labor cost.

Given data: Dozer maneuver time, average pass length, average speed.

Dozer travel distance equation:

$$TD = \frac{SD \times SW}{GW},$$

where TD = dozer travel distance (ft),

SD = slope distance (ft),

SW = slope width (ft),

and GD = grading width (ft).

Number of passes equation: See Dozer - Grade Level Area number of passes equation (A261..F280).

Dozer time equation: See Dozer - Grade Level Area time equation (A261..F280).

Cost: See Scraper - Subsoil Earthwork cost equation (A121..F140).

****** Dozer - Ripping Subsoil (A301..F320) ******

Description: Estimate costs to rip subsoil using a dozer.

Input data: Area to be ripped.

Data range: Dozer ripper width, hourly equipment operation, hourly labor cost.

Given data: Dozer maneuver time, average pass length, average speed.

Dozer travel distance equation:

$$TD = \frac{A \times 43560}{RW},$$

where TD = dozer travel distance (ft),

A = area to rip (acre),

and RW = ripper width (ft).

Number of dozer passes equation: See Dozer - Grade Level Area number of passes equation (A261..F280).

Total time is calculated by summing the time required for all passes with total ripping time at the given speed and then multiplying by 80% efficiency:

Dozer time equation: See Dozer - Grade Level Area dozer time equation (A261..F280).

Cost equation: See Scraper - Subsoil Earthwork cost equation (A121..F140).

TOPSOIL APPLICATION

****** Dozer - Topsoil Application (A321..F340) ******

Description: Estimate costs to haul and reapply topsoil using a dozer.

Input data: Haul distance, area to apply topsoil, topsoil depth that will be applied, average grade expected in the haul direction.

Data range: Dozer horsepower, hourly equipment operation, hourly labor cost.

Given data: None.

Production equation: See Dozer - Subsoil Earthwork production equation (A201..F220).

Dozer time equation:

$$T = \frac{(A \times 43560) \times TD}{P \times 27},$$

where T = dozer time (h),

A = area to apply topsoil (acre),

TD = topsoil depth that will be applied (ft),

P = production (yd^3/h).

Cost equation: See Scraper - Subsoil Earthwork cost equation (A121..F140).

****** Scraper - Topsoil Application (A341..F360) ******

Description: Estimate costs to haul and reapply topsoil using a scraper.

Input data: Haul distance, area to apply topsoil, topsoil depth that will be applied.

Data range: Scraper capacity, hourly equipment operation, hourly labor cost.

Given data: None.

Production equation: See Scraper - Subsoil Earthwork cost equation (A121..F140).

Scraper time equation:

$$T = \frac{(A \times 43560) \times TD}{P \times 27} \times \frac{1}{80\%},$$

where T = scraper time (h),

A = area to apply topsoil (acre),

TD = topsoil depth that will be applied (ft),

P = production (yd^3/h).

Scraper time is adjusted using an 80% operator efficiency factor.

Cost equation: See Scraper - Subsoil Earthwork cost equation (A121..F140).

****** Wheel Loader - Topsoil Application (A361..F380) ******

Description: Estimate costs to haul and reapply topsoil using a wheel loader.

Input data: Haul distance, area to apply topsoil, topsoil depth that will be applied.

Data range: Wheel loader capacity, hourly equipment operation, hourly labor cost.

Given data: Wheel loader operating speed, load-dump-maneuver time.

Wheel loader cycle time equation: See Wheel loader - Subsoil Earthwork cycle time equation (A141..F160).

Number of trips required is calculated by multiplying acres with topsoil depth for total volume to be moved and dividing this product by wheel loader capacity:

$$NT = \frac{(A \times 43560) \times TD}{C \times 27},$$

Number of trips equation:

where NT = number of trips,

A = area to apply topsoil (acre),

TD = topsoil depth that will be applied (ft),

and C = wheel loader capacity (yd^3).

Time equation: See Wheel loader - Subsoil Earthwork time equation (A141..F160).

Cost equation: See Scraper - Subsoil Earthwork cost equation (A121..F140).

**** Wheel Loader-Truck - Topsoil Application (A381..F420) ****

Description: Estimate costs to haul and reapply topsoil using a wheel loader to load topsoil and trucks to haul to the reapplication site.

Input data: Haul distance, area to apply topsoil, topsoil depth that will be applied.

Data range: Wheel loader and truck capacity, hourly equipment operation, hourly labor cost.

Given data: Truck and wheel loader operating speed, wheel loader load-dump-maneuver time, truck maneuver and dump time.

Buckets per truckload equation: See Wheel Loader-Truck - Subsoil Earthwork buckets per truckload equation (A161..F200).

Loader time per truck equation: See Wheel Loader-Truck - Subsoil Earthwork loader time per truck equation (A161..F200).

Truck loads required equation:

$$TL = \frac{(A \times 43560) \times TD}{TC \times 27},$$

where TL = truck loads required,

A = area to apply topsoil (acre),

TD = topsoil depth that will be applied (ft),

and TC = truck capacity (yd^3).

Truck cycle time equation: See Wheel Loader-Truck - Subsoil Earthwork truck cycle time equation (A161..F200).

Optimum number of trucks equation: See Wheel Loader-Truck - Subsoil Earthwork optimum number of trucks equation (A161..F200).

Total time per truck equation: See Wheel Loader-Truck - Subsoil Earthwork total time per truck equation (A161..F200).

Cost equation: See Wheel Loader-Truck - Subsoil Earthwork cost equation (A161..F200).

TOPSOIL GRADING

**** Dozer - Grading Level Areas, Topsoil (A421..F440) ****

Description: Estimate costs to grade topsoil on level areas using a dozer.

Input data: Area to be graded.

Data range: Dozer blade width, hourly equipment operation, hourly labor cost.

Given data: Average dozer speed, average pass length, dozer maneuver time.

Dozer travel distance equation: See Dozer - Grade Level Area dozer travel distance equation (A261..F280).

Number of passes equation: See Dozer - Grade Level Area dozer number of passes equation (A261..F280).

Dozer time equation: See Dozer - Grade Level Area dozer time equation (A261..F280).

Cost equation: See Scraper - Subsoil Earthwork cost equation (A121..F140).

**** Dozer - Grading Slopes, Topsoil (A441..F460) ****

Description: Estimate costs to grade topsoil on slopes using a dozer.

Input data: Slope distance, slope width, grade.

Data range: Dozer blade width, hourly equipment operation, hourly labor cost.

Given data: Dozer maneuver time, average pass length, average speed.

Dozer travel distance equation: See Dozer - Grade Level Area dozer travel distance equation (A261..F280).

Number of passes equation: See Dozer - Grade Level Area dozer number of passes equation (A261..F280).

Dozer time equation: See Dozer - Grade Level Area dozer time equation (A261..F280).

Cost: See Scraper - Subsoil Earthwork cost equation (A121..F140).

**** Motor Grader - Grading Topsoil (A461..F480) ****

Description: Estimate costs to grade topsoil on slopes using a motor grader.

Input data: Area to be graded.

Data range: Motor grader blade width, hourly equipment operation, hourly labor cost.

Given data: Motor grader maneuver time, average pass length, average speed, number of passes over one area.

Motor grader travel distance equation:

$$TD = \frac{P \times A \times 43560}{RW},$$

where TD = motor grader travel distance (ft),

A = area to grade (acre),

P = number of passes over one area,

and RW = effective graded width (ft).

Number of passes equation:

$$NP = \frac{TD}{PL},$$

where NP = number of passes,

TD = grader travel distance (ft),

and PL = grader pass length (ft).

Grader time equation:

$$T = \frac{TD}{S \times 88} + \frac{NP \times MT}{60} \times \frac{1}{80\%},$$

where T = grader time (h),

TD = grader travel distance (ft),

S = average grader speed (mi/h),

NP = number of passes,

MT = grader maneuver time (s).

Cost equation: See Scraper - Subsoil Earthwork cost equation (A121..F140).

REVEGETATION

**** Seed and Fertilizer Mix (A481..F560) ****

Description: Estimate costs for seed and fertilizer supplies.

Input data: Area to be seeded and fertilized, seed species, fertilizer types, seeding and fertilizer rates.

Data range: Seed and fertilizer costs (worksheet selected dependent on seed and fertilizer name).

Given data: None.

Seed cost equation:

$$C = \Sigma(UC \times SR \times A),$$

where C = cost ($),

UC = unit seed cost ($/lb),

SR = seeding rate (lb/acre),

and A = area to seed (acre).

Fertilizer cost equation:

$$C = \Sigma(UC \times SR \times A),$$

where C = cost ($),

UC = unit fertilizer cost ($/lb),

SR = fertilizing rate (lb/acre),

and A = area to fertilize (acre).

**** Mulch (A561..F580) ****

Description: Estimate costs for mulch supplies.

Input data: Area to be mulched.

Data range: None.

Given data: Mulch cost, application rate.

Cost equation:

$$C = UC \times SR \times A,$$

where C = cost ($),

UC = unit mulch cost ($/lb),

SR = application rate (lb/acre),

and A = area to mulch (acre).

****** Seed, Mulch, and Fertilizer Application (A581..F600) ******

Description: Estimate costs to apply seed, mulch, fertilizer.

Input data: Area to be applied, application method.

Data range: None.

Given data: Application cost.

Cost:

$$C = A \times UC,$$

where C = cost ($),

A = area to be applied (acre),

and UC = unit cost ($/acre).

****** Tracking Slopes for Temporary Erosion Control (A601..F620) ******

Description: Estimate costs to track topsoil on slopes for erosion control using a dozer.

Input data: Slope length and width.

Data range: Dozer blade width, hourly equipment operation, hourly labor cost.

Given data: Dozer maneuver time, average pass length, and average speed.

Dozer travel distance equation: See Dozer - Grade Level Area dozer travel distance equation (A261..F280).

Number of passes equation: See Dozer - Grade Level Area number of passes equation (A261..F280).

Dozer time equation: See Dozer - Grade Level Area dozer time equation (A261..F280).

Cost equation: See Scraper - Subsoil Earthwork cost equation (A121..F140).

****** Erosion Control Blankets (A621..F640) ******

Description: Estimate costs to purchase and install erosion control blankets.

Input data: Area to be applied.

Data range: None.

Given data: Unit cost.

Cost equation:

$$C = A \times UC,$$

where C = cost ($),

A = area to apply (acre),

and UC = unit cost ($/acre).

****** Planting Trees and Shrubs (A641..F660) ******

Description: Estimate costs to purchase and plant trees and shrubs.

Input data: Number of trees and shrubs of each size category.

Data range: None.

Given data: Unit cost.

Cost equation:

$$C = \Sigma(N \times UC),$$

where C = cost ($),

N = number of plantings,

and UC = unit cost ($/unit).

STRUCTURE DEMOLITION

****** Structure Demolition and Disposal (A661..F680) ******

Description: Estimate costs to demolish structures and to dispose of the debris.

Input data: Costs to demolish and dispose either on-site or off-site; process plant building, office building, equipment, trailers, foundations, pipelines, powerlines, telephone lines, fuel storage.

Data range: None.

Given data: None.

Cost equation: Sum of individual costs.

LINER DISPOSAL

**** Plastic Pond Liner and Pond Sediment Disposal (A681..F740) ****

Description: Estimate costs to dispose plastic liner either on-site or off-site.

Input data: Choice to remove or bury the liner and sediment, area of ponds to reclaim, total short tons of sediment to dispose, the distance the material will be hauled, plastic liner thickness in mils, the unit disposal fee per short ton of material to be disposed.

Data range: Backhoe capacity, backhoe hourly cost, backhoe hourly labor cost, general labor cost.

Given data: Person-hours required to fold in liner, the person-hours required to remove the liner from the pond, the unit haul cost in short ton-miles, sediment density, unit cement cost, unit time for using backhoe to mix cement into sediment, and backhoe cycle time.

Bury at-site liner cost equation:

$$BL = L \times 2 \text{ person-hours/Mft}^2 \times G,$$

where BL = cost to bury liner at-site,

L = total liner area (1,000 ft^2),

and G = general labor cost ($/hr).

Unit time for general labor to fold in the liner is assumed at 5 person-hours per 1,000 ft^2. Cost to bury liner does not include backfilling excavation.

Bury liner and sediment at-site cost equation:

$$BLS = BL + \frac{S}{40 \text{ st/hr mix time}} \times (BC + BLC),$$

$$+ UC \times CR,$$

where BLS = cost to bury liner and sediment at-site ($),

BL = cost to bury liner at-site ($),

S = amount of sediment to bury (st),

BC = backhoe hourly cost ($/hr),

BLC = backhoe hourly labor cost ($/hr),

UC = unit cement cost ($/st),

and CR = amount of cement required (st).

Backhoe production cost equation:

$$P = \frac{C}{CT} \times 60,$$

where P = backhoe hourly production (yd^3/hr),

C = backhoe bucket capacity,

and CT = backhoe cycle time (min).

Backhoe time required to load equation:

$$T = \frac{SL \times SD}{P \times 0.8 \times 27},$$

where T = backhoe time required to load (hr),

SL = amount of sediment to load (st),

SD = sediment density (cft/st),

and P = backhoe hourly production (yd^3/hr).

Operation efficiency is assumed at 80%.

Backhoe loading cost equation:

$$LSC = T \times (BC + BLC),$$

where LSC = backhoe loading cost ($),

T = backhoe time required to load (hr),

BC = backhoe hourly cost ($/hr),

and BLC = backhoe hourly labor cost ($/hr),

Remove sediment off-site cost equation:

$$RS = (UHC \times S \times HD) + (S \times UDF) + LSC$$

where RS = cost to remove sediment off-site ($),

UHC = unit haul cost ($/st-mi),

S = amount of sediment material to dispose (st),

HD = hauling distance (mi),

UDF = unit landfill disposal fee ($/st),

and LSC = backhoe loading sediment cost ($).

Remove sediment and liner off-site cost equation:

$$RLS = (L \times 10 \text{ person-hours to load/Mft}^2 \times G) + (UHC \times (LA + S) \times HD) + ((LA + S) \times UDF) + LC$$

where RLS = cost to remove sediment and liner off-site ($),

L = total liner area (1,000 ft^2),

G = general labor cost ($/hr).

UHC = unit haul cost ($/st-mi),

LA = amount of liner material to dispose (st),

S = amount of sediment material to dispose (st),

HD = hauling distance (mi),

UDF = unit landfill disposal fee ($/st),

and LC = backhoe loading cost ($).

Total disposal cost:

$$C = AS + OS$$

where AS = at-site disposal cost,

OS = off-site disposal cost,

and C = total disposal cost.

CAPPING HEAP

**** Capping Heap (A741..F880) ****

Description: Estimate costs to cap a heap.

Input data: Area to cap, thickness of clay liner, thickness of armor-drainage layer, haulage distances to clay and armor-drainage rock source.

Data range: None.

Given data: Unit operation and labor costs for a wheel loader, truck, and dozer.

Cost equation:

$$C = MHC + GC + CCC + MCC + MPC + MGC,$$

where C = cost ($),

MHC = material handling cost for clay ($),

GC = grading cost for clay ($),

CCC = clay compaction cost ($),

MCC = material for drainage layer crushing cost ($),

MPC = armor-drainage layer transport and placement cost,

and MGC = armor-drainage layer grading cost.

**** Other Costs (A881..F900) ****

Description: An option to include other costs that may be required that do not fit into other ranges in the worksheet.

Input data: Itemized costs.

Data range: None.

Given data: None.

Cost equation: Sum of itemized costs.

DETOXIFICATION METHODS

**** Detoxification Equations (M1..BU200) ****

CN in solution equation: If necessary, the average cyanide values may be estimated by,

$$CN_{av} = CN_{mx}/4,$$

where CN_{av} = average solution cyanide content (ppm),

and CN_{mx} = maximum solution cyanide content (ppm).

Heap volume equation: This is the total volume of the heap or heaps to be treated. Heap volume is dependent upon the tonnage of material contained and its density. The following equation is used in the spreadsheet for this calculation.

$$V = T \times 2{,}000/d,$$

where V = heap volume (ft^3),

T = amount of material contained in heap (st),

and d = heap material dry, unit density (lb/ft^3),

Pore volume equation: The pore volume of the heap is the total volume of the interstitial void space within the heap or heaps to be treated. The pore volume is calculated using the heap volume and the pore space. The equation used by the spreadsheet for this calculation:

$$PV = V \times pS/100,$$

where PV = a pore volume (ft^3),

V = heap volume (ft^3),

and pS = heap porosity (%).

Rinse volume equation: The total gallons of rinse water applied to the heap during treatment. Total gallons of rinse water applied to the heap is determined using heap pore volume, the number of pore volumes applied, and the gallons per cubic foot solution. The equation used by the spreadsheet for this calculation is:

$$TR = PV \times N \times (62.4/8.34),$$

where TR = volume of rinse water applied to the heap (gal),

PV = a pore volume (ft^3),

and N = number of pore volumes applied.

Total heap area equation: This is the total area of the heap to be treated. Area is calculated both as square feet and as acres. Total heap area is determined using heap volume and thickness. The equation used by the spreadsheet for this calculation:

$$A = V/t,$$

where A = total heap area (ft^2),

V = heap volume (ft^3),

and t = heap thickness (ft).

To convert to acres divide the number of square feet by 43,560 ft^2.

Total rinse water volume per area equation: This is the total gallons of rinse water applied to a 1-ft^2 area during treatment. Total gallons applied per square foot rinsed is determined using total heap area and total gallons of rinse water applied to the heap. The equation used by the spreadsheet for this calculation is:

$$TV = TR/A,$$

where TV = total rinse water volume per unit area of heap (gal/ft^2),

TR = volume of rinse water applied to the heap (gal),

and A = total heap area (ft^2).

Rinse panel cycle equation: This is the amount of time required to circulate the designated number of pore volumes through one panel. No adjustment has been made for setup or down time. It is assumed that all rinse campaigns will treat equal-sized panels at the designed capacity. The length of the rinse cycle is determined using the total amount of rinse solution applied per square foot and the application rate. The equation used by the spreadsheet for this calculation is:

$$C = \frac{TV}{r \times 60 \times 24},$$

where C = rinse cycle length (days),

TV = total rinse water volume per unit area of heap (gal/ft^2),

and r = application rate ($gal/min/ft^2$).

Number of rinse panels equation: The number of rinse panels that will be treated rounded upward to the nearest whole number. It is assumed that all rinse panels will treat equal areas. Total rinse panels are determined using the area of the heap and the area rinsed at one time. The equation used by the spreadsheet for this calculation is:

$$NC = A/a.$$

where NC = number of rinse panels,

A = total heap area (ft^2),

and a = area to be rinsed per cycle (ft^2),

Total cyanide to treat equation: This is the amount of cyanide that will be chemically neutralized through the proposed detoxification method. Pounds of neutralized cyanide are determined using the average rinse solution cyanide content; the heap thickness, area, and porosity; and the number of pore volumes recirculated. The equation used by the spreadsheet for this calculation is:

$$CN_a = t \times A \times (pS/100) \times N \times 62.4 \times (CN_{av}/1{,}000{,}000),$$

where CN_a = amount of cyanide to treat (lb),

t = heap thickness (ft),

A = total heap area (ft^2),

pS = heap porosity (%),

N = number of pore volumes applied,

and CN_{av} = average cyanide content in effluent (ppm CN).

Pump rate equation: This is the rate at which rinse solutions are recovered from the treatment tank or storage pond for reapplication to the heap. The pumping rate is determined using the total volume of rinse solution applied per 1-ft^2 area of heap, the number of days per rinse cycle, and the area under rinse in a panel. Evaporation is accounted for in the equation by multiplying by a factor of 1.20. The equation used by the spreadsheet for this calculation is:

$$PR = \frac{1.2 \times TV \times a}{C \times 24 \times 60},$$

where PR = pumping rate (gal/min),

TV = total rinse volume per unit area of heap (gal/ft^2),

a = panel area to be rinsed per cycle (ft^2),

and C = rinse cycle length (days).

Reagent feed rate equation: Depending upon the process under consideration, various reagent consumption rates are used including lime, hydrogen peroxide, chlorine, and sulfite. Reagent consumption is determined using rates found in the supplies portion of the cost analysis below. The equation is based on the maximum solution cyanide content, and the ratio between cyanide treatment and reagent requirements. The equation used by the spreadsheet for this calculation is:

$$F = \frac{CN_{mx}}{10^6} \times PR\ 8.34 \times RC$$

where F = reagent feed rate (lb/min),

CN_{mx} = maximum cyanide solution content (ppm CN),

PR = pumping rate (gal/min),

RC = reagent use per pound cyanide (lb/lb CN).

Reaction tank volume equation: This is the size of the reaction vessel. (Treatment tank volume is determined by retention time and pumping rate). The equation used by the spreadsheet for this calculation is:

$$TV = R \times PR \times 8.34/62.4,$$

where TV = treatment tank volume (ft^3),

R = tank retention time (min),

and PR = pumping rate (gal/min).

Reagent tank volume equations: This is the size of individual reagent storage tanks on-site. Individual reagent tanks are sized using the reagent use rate calculated earlier. In general, it is best to use the maximum reagent consumption rate rather that the average for this calculation. If supplies are nearby, it may be possible to reduce the number of days' supply held on-hand. The equation also includes a factor for the number of days' storage maintained assumed to be one week, and the density of the material being stored. The equation used by the spreadsheet for this calculation is:

$$SV = \frac{F \times 24 \times 60 \times 7}{Dr}$$

where SV = storage tank volume (ft^3),

F = reagent feed rate (lb/min),

and Dr = material density (lb/ft^3).

Reagent consumption equation: This value is calculated for each reagent using:

$$RU = (TR/T) \times 8.34 \times RC \times CN_{av}/10^6,$$

where RU = reagent use per unit weight of heap material (lb/st),

TR = volume of rinse water applied to the heap (gal)

T = amount of heap material (st),

RC = the reagent consumption per pound cyanide treated (lb/lb CN),

and CN_{av} = average cyanide content in effluent (ppm CN).

Reagent cost per short ton equation: The cost per short ton heap material treated for each reagent is calculated by,

$$TRC = RU \times RUC,$$

where TRC = specific reagent cost ($/st),

RU = reagent use per unit weight of heap material (lb/st),

and RUC = unit reagent cost ($/lb).

Piping cost equation: The unit cost for piping is calculated by,

$$PCT = \frac{0.5 \times (Pc - Mc)}{(T/N - 1)},$$

where PCT = piping cost per unit short ton of heap material ($/st),

Pc = total panel piping costs from capital cost section below,

Mc = mainline piping costs from pump to heap costs,

T = total tonnage on heap,

and N = number of rinse panels.

Total project supplies cost equation: The project cost for each reagent and for piping charges are calculated by,

$$TSC = (TRC + PCT) \times T,$$

where TSC = total project supplies cost ($),

TRC = total project specific reagent cost ($/st),

PCT = piping cost per unit weight of heap material ($/st),

T = amount of heap material (st),

Royalty unit cost equation: The royalty cost per short dry ton of heap material treated is determined by:

$$Y = RU \times y,$$

where Y = royalty unit cost ($/st),

RU = reagent use per unit weight of heap material (lb/st),

and y = base royalty rate ($/lb sulfite).

Total project royalty cost: The project cost for the royalty is calculated by:

$$Trc = T \times Y,$$

where Trc = total project royalty cost ($),

T = amount of heap material (st),

and Y = royalty costs per short ton treated ($/st).

Calculated equipment ratings equations: In the equipment operation ranges for the treatment process, most ratings are calculated on the basis of throughput. As the format for these calculations varies for each equipment type, a detailed description of these formulas is not included here; however, individual equations may be reviewed in the spreadsheet. In these cases, the numbers computed should be viewed as minimum values, guides to actual capacities used to determine hourly charges in the cost references.

Electricity equation: The electrical costs are computed by,

$$E = HP \times (e/100) \times 0.7457,$$

where E = total hourly charges for each piece of equipment,

HP = the horsepower rating of the equipment motor,

and e = the local power cost rate in cents/kW·h.

APPENDIX F.—BOND CALCULATION EXAMPLE

An example reclamation performance bond calculation for a hypothetical heap leach facility is included on the HEAPREC diskette and labeled EXAMPLE.WK1. EXAMPLE.WK1 was included to allow the user immediate access to a reclamation bond calculated with HEAPREC. Use EXAMPLE.WK1 to become familiar with how HEAPREC works. Modify data inputs in EXAMPLE.WK1 and analyze how different parameters and assumptions affect the overall cost of a bond. Use EXAMPLE.WK1 to compare the relative costs for using different sizes and/or types of earthmoving equipment for completing the same task. See what input parameters have the greatest or least impact on cyanide detoxification costs. Notice that all four of the cyanide detoxification methods were evaluated for cost comparison purposes; however, only the fresh water rinse procedure was included in the bond estimate.

A brief description of the site, assumed disturbances, and planned reclamation activities used in EXAMPLE.WK1 are presented below. Refer to EXAMPLE.WK1 for the actual inputs used. The amount of detail presented below is not dissimilar from the type of data found in preliminary reclamation plans submitted to initiate the permitting process.

EXAMPLE.WK1 PROPOSED SITE RECLAMATION PLAN

The following is the proposed reclamation plan for the EXAMPLE Mine and associated heap leach facilities located in central Nevada.

The goal of reclamation will be to stabilize the natural and biological processes on the site by regrading and revegetating disturbed lands. The primary intent of this activity is to accelerate the natural invasion and succession processes at the site.

All disturbed areas will be regraded to the approximate original contours, except for heaps and mine dumps which will be reshaped to blend into the surrounding topography. Compacted areas will be ripped on contour to a depth of 1 to 1.5 ft, salvaged topsoil will be spread as judiciously as possible with preference to applying topsoil to facilities and heap areas first, and seed will be broadcast then covered using a harrow. Revegetative succession, determined after two growing seasons, will be based on pre-existing vegetative cover in the area of 5% to 15%. A list of the disturbed areas including dimensions of the disturbance and planned reclamation are presented below:

HEAPS: Heaps 1 and 2 will respectively contain 5.25×10^6 st and 1.75×10^6 st of agglomerated material. Heaps will be detoxified using fresh water rinsing, lab-scale testing show that four pore volumes of rinsate will reduce CN_F levels below state standards. Heap heights average 75 ft. Slope faces will be reduced from 2:1 to 3:1.

BUILDINGS: The office and plant steel-framed buildings will be disassembled, with salvage considered, rubbish will be disposed of in an approved on-site solid waste disposal area. Modular structures will be removed. All areas including foundations will be topsoiled and vegetated.

PONDS: Once heap detoxification is completed, the solutions in the pregnant and barren ponds will be detoxified and disposed of according to state requirements. Accumulated sludge will be tested and disposed of as per state requirements. Synthetic pond liners will be folded over and buried in place, associated depressions will be filled in, and the area will be topsoiled and seeded.

ROADS: All access, haul, and unreclaimed exploration roads will be brought back to original contour, ripped if needed, and seeded. Every effort will be made to reclaim exploration roads concurrent to termination of use.

MINE WASTE DUMP: The dump crest will be rounded and shaped to blend into the existing topography. The top of the dump will be ripped and all dump surfaces will be seeded.

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